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TARAYANA FOUNDATION

A STUDY AND SURVEY ON KEY INVASIVE PLANT SPECIES IN SOUTH WESTERN BHUTAN

Tarayana Foundation
is working together
with partners to
secure High
Conservation Values
in south-western
Bhutan

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A STUDY & SURVEY ON KEY INVASIVE PLANT SPECIES IN SOUTHWESTERN BHUTAN

TARAYANA FOUNDATION
Thimphu, Bhutan

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ABBREVIATION AND ACRONYM

AHP	Analysis of hierarchical Process
AUC	Area under curve
BBS	Bhutan Broadcasting Service
Chiwog	Sub-block
Dzongkhag	Dzongkhag
Gewog	Block
GIS	Geographic Information System
GPS	Global Positioning System
IKI	International Climate Initiative
IPS	Invasive Plant Species
IUCN	International Union for Conservation of Nature
NBC	National Biodiversity Centre
NBSAP	National Biodiversity Strategies Action Plan
NFE	Nonformal education
RGoB	Royal Government of Bhutan
RNR	Renewable Natural Resources
ROC	Receiver operating characteristics
SDM	Species Distribution Modelling
TF	Tarayana Foundation

EXECUTIVE SUMMARY

This study is a part of International Climate Initiative (IKI) funded project focusing on Study of Key Invasive Plant Species and Community Training under the Project Living Landscapes: Securing High Conservation Values in Southwestern Bhutan. The study aims to achieve the following objectives: Identification of key Invasive Plant Species (IPS) using artificial keys and morphological characteristics; community awareness on and local management techniques of IPS; and geospatial mapping using Geographic Information System (GIS), and distributional prediction using species distribution modelling (SDM).

Detection of presence of IPS was administered using footpath transect cutting villages along the altitudinal gradients and household survey using questionnaire-based interview. Household survey consisted of questions on awareness or knowledge on IPS, their sources of introduction and impacts on environment, infrastructure, crop productivity and the local IPS management techniques. Global Positioning System (GPS) was used to collect the locations of IPS to be analysed in GIS and mapping, and species distribution modelling.

Internationally recognized IPS such as *Ageratina adenophora, Ageratum conyzoides, Chromolaena odorata, Parthenium hysterophorous, Mikania micrantha* and *Lantana camara* have been detected during the study. The study also has come across some recently introduced IPS such as *Eichornia crassipes, Pennisetum clandestinum* and *Trifolium repens,* and many other miscellaneous IPS or agricultural weeds. IPS were perceived to have been mostly introduced as feed and fodder for livestock, plantations and through transportation of goods. Elderly people are more knowledgeable on identification and management of IPS. Most of IPS have negative impacts on crop productivity due to competition with crops and native plant species, and labour cost of removing them. IPS control is mainly done manually using techniques such as uprooting and burning. Communities also suggest that awareness on IPS by the relevant agencies is very important and thus

the agents (e.g., RNR staff) should be knowledgeable in different techniques of control and prevention measures.

Geospatial analysis, such as invasion index mapping, alludes that area prioritization may be important in addition to species prioritization to achieve an effective prevention or control measures of invasion by IPS. For instance, study gewogs, such as Dorona, Gakiling, Laja, Logchina and Metakha are found to be vulnerable to invasion due to high invasion index. Also, the herbaceous IPS are to be given the priority of prevention in areas that have not yet been invaded and control in areas that have already been invaded since these species are found to cover almost all types of land use and land cover in the study areas.

Six IPS have been recognized as most damaging by the communities as well as by the results of geospatial modelling. According to the invasion vulnerability assessments, most of the southern gewogs were found exposed to the invasion while western gewogs were not. The key finding of the study suggests that new species introduction can lead to disproportionate invasion of the landscape. For example, Kikuyu grass and white clover have been predicted to have almost indiscriminate invasion across all the study sites as per the MaxEnt Model. These two species so far have not been officially recorded as noxious species in the country. Therefore, the study carries a set of recommendations on prioritization of management, management techniques for major IPS with seasonal calendar, some recommendations on legislative measures and a field manual to be used by the field officer to train farmers in managing the IPS in the study area.

INTRODUCTION

The study and survey of key invasive plant species (IPS) is a project under the Project Living Landscapes: Securing High Conservation Values in Southwestern Bhutan that is part of the activities implement by Tarayana Foundation with fund support by the International Climate Initiative (IKI). The rationale of the study is that biological invasion has now become a global problem causing huge losses to economy through negative impacts on crops, animal and human health, and more importantly biodiversity loss (Auld, 1977; Baxter, 1995; Bhardwaj, Kapoor, & Singh, 2014; Choudhury, 1972; Choudhury et al., 2016; Constance et al., 2007; Crossman, Bryan, & Cooke, 2011; D'Antonio & Vitousek, 1992; Day et al., 2016; DiTomaso, 2000; Dogra et al., 2010; Hejda, Pyšek, & Jarošík, 2009; Kanchan, 1980; Kannan, Shackleton, & Shaanker, 2014; Pejchar & Mooney, 2009; Sankaran & Suresh, 2013). For example, in the USA, the annual cost of crop losses due to invasion and controlling invasive plants accounts to over US$ 40 billion (Pimentel et al., 2000). In the developing countries agriculture remains as a primary economic sector, where pests and pathogens cause loss in crop productivity (Paini et al., 2016). Invasion has detrimental effects on biodiversity by disrupting ecosystem services, such as competitive exclusion of native species due to modification of habitat by invasive plants (Simberloff & Von Holle, 1999).

Invasion by IPS is caused by different vectors and pathways. Vectors of invasion can be natural or manmade. Natural vectors include birds, animals, wind and water. Manmade vectors include stowaways on air or ship ballast. Since globalization of economy, the invasion rate has increased due to import for different economic purposes- fodder, medicines, ornaments, and conservation. Trade and travel are believed to be exposing the country to foreign invasive species (Bhutan Broadcasting Service [BBS], May 24, 2018). Further, the climate change is said to facilitate the invasion since IPS are characterised by high plasticity of adaptation to different climatic conditions (International Union for Conservation of Nature [IUCN], 2021).

Bhutan is recognized as a biodiversity hotspot by accounting for more than 5603 species of vascular plants out of which 46 were reported to be invasive species (NBC, 2009; NBSAP, 2014; RGoB, 2012). According to the national report on IPS (NBSAP, 2014), there are limited strategies and plans to address the problems in Bhutan. This study therefore attempts to address the issues of IPS using three approaches as follows:

1. Field botany identification and description of key IPS;
2. Evaluation of people's perceptions on invasion;
3. Mapping the locations of and spatial prediction of IPS.

To achieve these objectives, approaches were adopted as shown under the section Materials and Methods.

General Methods and Ideation

Field and household surveys were used to study the IPS. Each survey covered the components as shown in Fig. I. The techniques of each survey are described as follows.

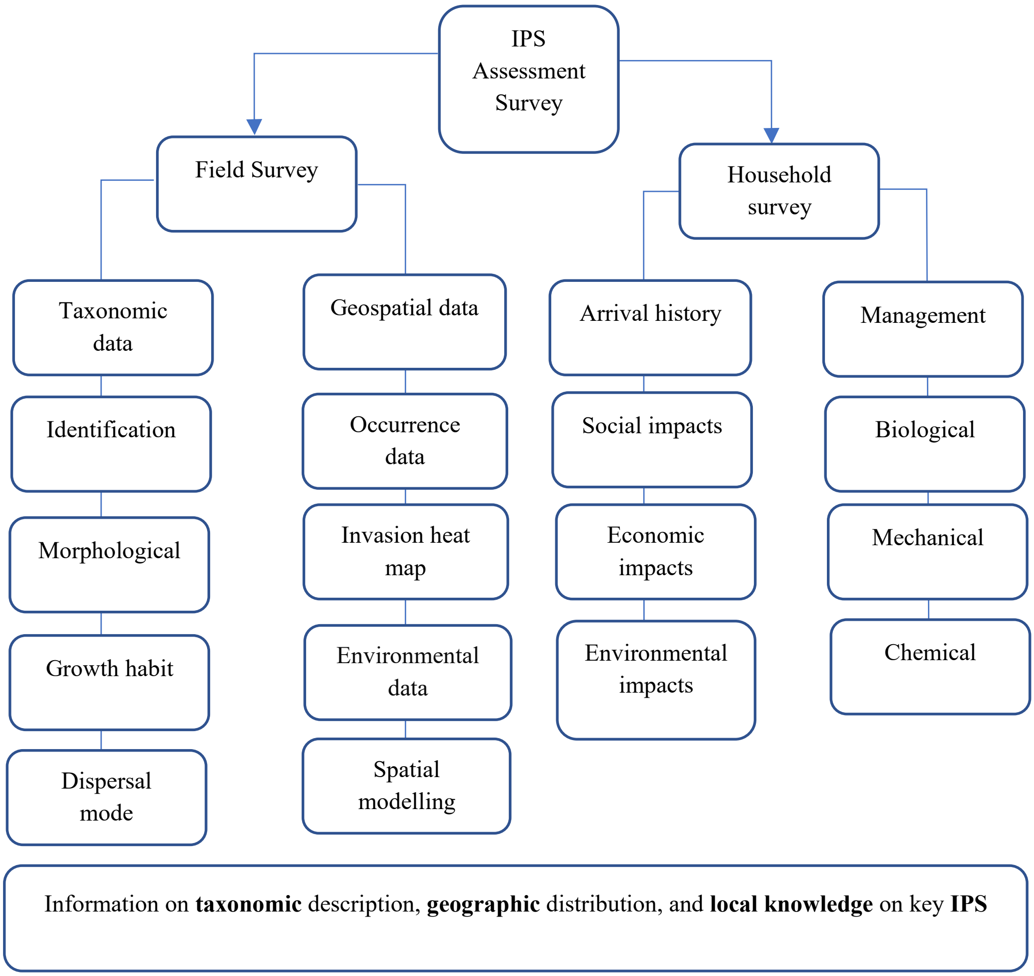

Fig. I: Conceptual Framework

Field survey

In the field survey, two major types of data were collected. (i) Taxonomic data were gathered comprising species identity, morphological characteristics, growth habit, (ii) Geolocation was recorded using GPS ID and coordinates of the species occurrences were recorded in GPS units along with description of land use types, ecological zones, and cover percent.

Household survey

Face to face household survey was conducted in the study sites. Demographic parameters such as age, gender and education were considered. The respondents were interviewed on the IPS introduction history (pathways, corridors, purposes), its economic, social, and environmental impacts and as well as the management practices they use to prevent, control or eradicate IPS in their locality based on the idea as shown in Fig. II.

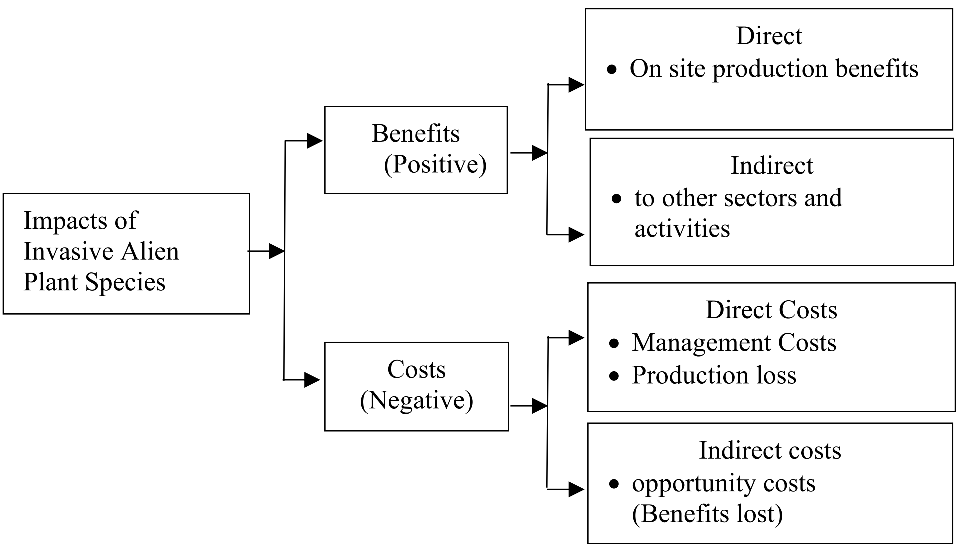

Fig. II: Classification of positive and negative effects of invasive species (Adapted from Emerton, L. and G. Howard, 2008).

SECTION I: IPS IDENTIFICATION AND DESCRIPTION

1.1 Materials

Data collection sheet, GPS, plant press, digital camera, newspapers, pencil/pen, stapler and stapler pins, 1 x 15 cm paper stripes and polythene bags were used in data collection. Photographs of plants with details of habits, flowers, leaves, fruits and any other feature relevant for identification were photographed. Identification was done based on the book Flora of Bhutan, consisting of eight volumes (Grierson and Long 1983), Weeds of Bhutan (Parker, 1992).

1.2 Data Collection

Information on the presence of IPS were collected in the field through transects and questionnaire survey. Transects included a) footpath transect cutting through the villages along altitudinal gradient and b) transect along the road, recording roadside species. In either of the cases, the surveyors walked downhill from higher to lower altitude to cover longer transects in the shortest time possible.

During transects, 4 m x 4 m quadrats were used to collect the species information. In each transect, the quadrats were placed in the beginning, at the end and several in between depending on the size of the study area as well as detection of IPS. The length of transects determined the number of quadrats in each transect. All invasive alien species found in each quadrat were recorded in terms of percentage cover. Distance between quadrats were not fixed but was decided by every new invasive species encountered during the survey transects.

1.3. Identification and Description of IPS

1.3.1 Scientific name: *Ageratina adenophora*
Family: Asteraceae
Common names: Assam, Crofton weed, eupatory, Mexican devil, kali jhar.
Description: Perennial herbaceous shrub growing to about 2 metre tall, but generally below a metre tall. Stems are with swollen node, blackish in colour. Leaves are trowel shaped and margins are serrated. Inflorescence is a head of about 0.5 cm. Florets are white. Seeds are brown and parachute-like.
Distribution: Originally native to Mexico, Central America, but is a pandemic noxious weed. It is now found in Chukha (Logchina and Maedtabkha), Dagana (Dorona and Laja), Haa (Gakiling), Tsirang (Patsaling and Puentenchu), and Samtse (Dophuchen).
Impacts: It occupies moist, marshy and damp soil. It invades barren land similar to pioneer species and can spread both by seed dispersal and vegetatively. It has allelopathic effect on other plants and causes significant agriculture crop and biodiversity losses. It is toxic to horses and cattle.
Management: In the study area, it is mostly managed by uprooting and cutting in the area; easier uprooted in summer than in winter. However, elsewhere it is managed with limited success using mechanical, biological and chemical control. Biological control is still under trial using a stem-galling fly, *Procecidochares utilis*, and a leaf spot fungus, *Phaeoramularia* sp. This species flowers through most part of summer. Therefore, it is cut or uprooted before the plant flowers. May and June months are better for management and control of this species.
Uses: The plants can be converted to compost. Crushed leaves are used in cut wound to stop bleeding by the local people.

Fig 1.1: *Ageratina adenophora* in flowers

1.3.2 Scientific name: *Ageratum conyzoides*

Family: *Asteraceae*

Common names: Chick weed, Elamey, Goatweed, seto rawanne jhar

Description: It is an annual herb growing up to 1 metre tall but is generally less than half a metre in height. Stem, leaves and inflorescence are hairy. Flowers are white to bluish in colour and occur in heads. Leaves are stalked and ovate to lance-like with toothed margins. Seeds are dark and needle like.

Distribution: Originally from tropical America, Brazil mainly, but it is a pandemic noxious weed. It is found in Chukha (Logchina and Maetabkha), Dagana (Dorona, Laja), Haa (Gakiling), Tsirang (Tsirangtoed and Phuentenchu), Samtse (Dophuchen) and Sarpang (Samtenling).

Impacts: It is a wide spread agricultural weed, but farmers usually do not consider this species as weeds and treat it as a useful plant.

Management: It is controlled by weeding and tillage since it occurs mostly in agricultural lands. Short periods of flooding can used as well. As of now there are no biological control agents, but there are wide range of herbicides.

Uses: Farmers in the study area use it for mulching or as green compost as it can decay easily. Crushed leaves are used in cut wounds to stop bleeding.

Outside Bhutan, it is used for treating diarrhoea and dysentery. It can be also used as insecticide and nematicide.

Fig 1.2: *Ageratum conyzoides* in flowers

1.3.3 Scientific name: *Chromolaena odorata*

Family: Asteraceae

Common names: Assamey, Christmas bush, devil weed, Siam weed.

Description: Perennial shrub growing to about 2.5 metre tall but can be found as straggling shrub in shady areas. The plant is hairy with triangular leaves and white flowers in heads. Seeds are elongated and light which are easily dispersed by wind.

Distribution: The plant is native to tropical Americas, but is a pandemic weed. In the study areas it is found in Chukha (Logchina and Maetabkha), Dagana (Dorona and Laja), Haa (Gakiling) Samtse (Dophuchen), Sarpang (Samtenling) and Tsirang (Tsirangtoed, Patsaling and Phuentenchu) dzongkhag. It is mostly found below 1000 m above sea level

Impacts: It primarily invades fallow and waste lands in the tropical and subtropical zones. However, it was found abundant in cardamom and mandarin orchards in the study areas. It is known to affect field crops and can significantly alter composition of native biodiversity.

Management: It is mostly controlled by cutting and burning. However, both the biological and chemical control had been tried with some success. Stem-galling fly, *Cecidochares connexa* was found to significantly decrease cover, height and density of *Chromolaena odorata* in Papua New Guinea. Cutting of the plant before flowering begins is the best management option for its control.

Uses: The plant can be useful in recycling nutrient and soil improvement in shifting cultivation. It has ethno-pharmacological, fungicidal, and nematicidal properties.

Fig. 1.3: *Chromolaena odorata* in flowers

1.3.4 Scientific name: *Mikania micrantha*

Family: Asteraceae

Common names: American rope, bitter vine, climbing hemp vine, japaney, jiljiley lahara, tite lahara.

Description: It is a fast-growing perennial, scrambling or climbing vine often found climbing over trees. Leaves have stalks and are heart shaped. Flowers are white in heads. Seeds are linear and black, have pappus with bristles – enabling them to be dispersed by wind.

Distribution: It is native to Americas, but is a pandemic weed. In the study areas, it is found in Chukha (Logchina and Maedtabkha), Dagana (Dorona and Laja), Samtse (Dophuchen), Sarpang (Samtenling) and Tsirang (Tsirangtoed, Patsaling and Phuentenchu) Dzongkhags up to 1000 m above sea level.

Impacts: It is a widespread vine in the tropical and subtropical zones invading wasteland, orchards and agricultural crop lands. It mostly occupies moist areas and is found to have destroyed mandarin and cardamom fields completely. It is known to be allelopathic, inhibiting growth of other plants.

Management: In the study area, it is mostly managed by cutting and burning. Elsewhere, it is managed using mechanical, biological and chemical control measures. Predatory thrips, ants and spiders are found to be the effective natural enemies of *Mikania micrantha*.

Uses: The plants are good in compost making and are used in treating cut wounds and various ailments. It is used as fodder for cattle and goat. However, it is known to cause liver damage in cattle.

Fig. 1.4: *Mikania micrantha* in flowers

1.3.5 Scientific name: *Opuntia monacantha*

Family: Cactaceae

Common names: Barbary fig, prickly pear, drooping prickly pear, jawairinga tsang.

Description: Erect or sprawling shrub growing to 5 metres with thick ovate-flattened segments of succulent stem covered by thorns. Leaves are small to about 2-3 mm long or are modified. Flowers are large, up to 8 cm, yellow and showy. Fruits are pear-shaped or obovoid and have bristles.

Distribution: Native to South America but is widely introduced. It occupies mostly dry subtropical and tropical areas. However, it was observed growing well by roadside in Gidakom, Thimphu at about 2400 m above sea level.

Impacts: It occupies degraded and barren land capable of invading agriculture land.

Management: Once the plant has established it is very difficult to control its further spread. It has been successfully controlled around the globe using biological control measures. The insect called *Dactylopius ceylonicus* and the cactus moth, *Cactoblastis cacturum* can destroy the *Opuntia monacantha.*

Uses: Fruits are edible, but the bristles can be irritants. In Bhutan, the thick fleshy stems are boiled and fed to pigs. It can be used as live fencing with management caution.

Fig. 1.5: *Opuntia monacantha* in flower

1.3.6 Scientific name: *Cenchrus clandestinus* (Syn. *Pennisetum clandestinum*)

Family: Poaceae

Common names: Kikuyu, hatti dubo, ja-dram, sung-cha.

Description: Perennial rhizomatous grass with matted roots at nodes. Stem jointed and leaves are linear with sheaths.

Distribution: Native to east Africa, but widely introduced in golf courses, as lawn grass and for pasture. In Bhutan, it was introduced as pasture species in the temperate region. It is found in Chukha (Maedtabkha), Dagana (Dorona), Paro (Dokar), and Thimphu (Mewang) dzongkhags.

Impacts: It occupies dry cultivated land as well as waste land. It is encroaching agriculture land affecting agriculture crop production. Its' stolon and root system can form thick mat and produces herbicidal toxin that inhibits other plants to grow. While it is a preferred pasture species, it is believed that it spreads through partially digested stolon stubs of the eaten grass through cattle dung. Kikuyu is also noted to flower spread through seeds, but in Bhutan there is no evidence that it spreads through seeds.

Management: It is managed by uprooting, disking and cutting, but will emerge again if there is small part of the broken stolon left behind. There is no biocontrol measure to this species.
Uses: Kikuyu is used as a lawn grass and is a preferred fodder species.

Fig. 1.6: Kikuyu grass invading dryland in Chukha

1.3.7 Scientific name: *Parthenium hysterophorus*

Family: Asteraceae
Common names: bitter weed, carrot grass, congress grass, famine weed, feverfew, Santa-Maria and whitetop weed among others.
Description: Herbaceous annual plants growing to about 1 metre tall. Stems, leaves, and inflorescences are hairy. Leaves are simple and lobed. Flowers are borne in heads, which bear several small florets – individual flowers in the head. Sepals and petals are white.
Seeds are parachute like achenes which are spread by wind, water and animals, and through transportation and trade.
Distribution: Originally native to Central America and Caribbean. Now it is a pandemic weed spreading mostly in semi-arid tropical, sub-tropical and warm temperate regions of the world. In Bhutan, it has spread below 1500m

throughout the country including on riverbanks. In the study area, it is found in Dagana (Laja), Tsirang (Tsirangtoed) dzongkhags.

Impacts: Occupies barren areas, open mineral soil, roadsides, pasturelands, uncultivated fallow land, and wasteland especially at lower altitude – below 1500 metre above sea level. It can cause disastrous failure of crop production as the plant produces alellopathic chemical that inhibits growth of other plants and is befittingly called famine weed. Contact with the plant causes allergies to livestock and people.

Management: In cropland, plants can be hoed or weeded – uprooted. Use of chemicals such as Glyphosate is not the first choice since it harms non-target organisms and contaminates soil. When young, before the seeds are formed, plants can be collected and converted into bio-fertilizer and can be used in biogas plants. In Australia and some parts of Asia, biological control has been tried with some success. However, in some countries such as in Kenya, farmers are required to keep their agriculture land free from this weed by legislation.

Uses: The plants can be used in compost and green manure making. The allelopathic substance has potential to be used as herbicide, nematicide, fungicide and insecticide. It is used in silkworm rearing and has potential to make protein rich livestock feed.

Fig. 1.7: *Parthenium hysterophorus* in flowers

1.3.8 Scientific name: *Robinea pseudoacacia*

Family: *Fabaceae*

Common names: black locust, false acacia

Description: It is a deciduous tree growing usually to about 30 metre tall and has been noted to grow up to 50 metres. Young trees are usually spiny. Leaves are compound with leaflets. Flowers are borne on branched inflorescence, flowers white-cream, flower bunch drooping. Pods are pea like and dark brown containing about 4 to 8 seeds.

Distribution: It is thought to be native to North America, but it is widely introduced, and its native range is still uncertain. In the study areas, it is noted in Thimphu (Gidakom) by roadsides, perhaps introduced as avenue trees.

Impacts: It occupies degraded soil and wasteland in the temperate zone. It is known to invade dry agriculture land as well. Besides from seeds, the species can reproduce from root suckers. Since it is a nitrogen fixing species, it has environmental effect as it can change species composition and affect local biodiversity. It is also known to affect animal health and ecosystem services. It is known to be toxic to humans and animals, especially the horses.

Management: Due to the habit of spreading through root suckers, it is difficult to control its spread. However, chemical control is tried with some success.

Uses: Despite its invasive nature, black locust is used as a multipurpose tree species in agroforestry and is a source of acacia honey. It is used in avenue plantation, as cattle feed (with caution due to toxicity), for firewood and charcoal, as timber, in veneer production and other wood products.

Fig.1.8: *Robinea pseudoacacia* in fruits

1.3.9 Scientific name: *Tagetes minuta*

Family: *Asteraceae*

Common names: black mint, stinking roger, southern marigold, wild marigold.

Description: It is annual woody herb growing to about 2 metre tall. Stems have grooves or ridges. Leaves are compound with pinnae – with small leaflets. Flowers are in small heads consisting of ray and disc flowers/florets flowers yellow-orange or whitish orange. Seeds are dark brown and have awns.

Distribution: Native to South America, but is a pandemic weed of wasteland. In the study area, it is found in Thimphu, (Gidakom).

Impacts: It occupies moist and dry areas, invading mostly the abandoned or wasteland. While it is a tropical and sub-tropical species, it is also noted in the temperate region. It is also noted to invade poorly farmed agriculture land such as maize field and can reduce crop yield substantially. The plant is irritants to farmers and the plant sap odour is objectionable.

Management: It is easily controlled by weeding or up-rooting, but this should be done before flowering. It can also be controlled using herbicides.

Uses: Worldwide, it is considered as an aromatic plant and is used in extraction of marigold oil or tagetes oil, which is an essential oil. The oil is used in favouring many food products, as laxative and medicine, insect repellent, and in perfumery. Plants can be used as green tea and in beverage industry. Extracts from the plant can be used as insecticide and nematicide.

Fig. 1.9: *Tagetes minuta* in flowers

1.3.10 Scientific name: *Cosmos bipinnatus*
Family: *Asteraceae*
Common names: garden cosmos, Mexican aster
Description: Annual herb growing to about 2 metres. Stems are smooth or hairy. Leaves are linear and thread like. Flowers are of various coloured and attractive. Seeds are spindle shaped and black in colour.
Distribution: Native to Americas, but is an invasive weed. Thimphu (Gidakom).
Impacts: It occupies degraded, abandoned, and barren land in the temperate areas spreading well in open mineral soil. It can reduce local biodiversity and invade cultivated dryland such as maize field.
Management: The garden cosmos is generally managed by weeding. However, it can be controlled by cutting before the plant flowers.

Uses: The garden cosmos is beautiful ornamental plant and is also popular as cut flower. It is non-toxic and the young leaves had been used in salad preparation and dissert brightening or decoration. The plant is also used in preparing anti-inflammatory ointment. Flowers are source of nectar for bees.

Fig. 1.10: *Cosmos bipinnatus* in flowers

1.3.11 Scientific name: *Tithonia diversifolia* (Hemsley) A. Gray

Family: *Asteraceae*

Common names: Mexican sunflower, Japanese sunflower, *taraphul*, tree marigold.

Description: Generally, a perennial shrub growing to about 3 metre tall. Leaves are sub-ovate, margin toothed, and simple or lobed. Flowers heads are large, showy and yellow. Seeds are black, angled and elongated; usually dispersed by wind.

Distribution: It is native to Mexico and Central America but is widely introduced. In the study area, it was observed in the subtropical zone of Chukha (Logchina) dzongkhag.

Impacts: It can grow in nutrient poor soil and can resist draught to certain extent. It can spread very fast in barren and waste land. It can cause significant loss of native biodiversity.

Management: It can be controlled by cutting and burning. *Physonota maculiventris* (Coleoptera: Chrysomelidae), a leaf-feeding beetle, was found as an effective biological control in Mexico. Herbicides such as triclopyr, picloram, metsulfuron-methyl and 2,4-D may be resorted to if the spread is extensive.
Uses: The plant is used for composting and as green fertilizer, feeding chicken and goats, mulching agriculture crops, as ornamental plant, fuelwood and building materials.

Fig. 1.11: *Tithonia diversifolia* in flowers

1.3.12 Scientific name: *Pontederia crassipes* (Syn. *Eichhornia crassipes*)
Family: *Pontederiaceae*
Common names: common water hyacinth.
Description: Free-floating perennial aquatic plant which may rise to 1 metre high above water surface. Stems have bulb-like nodules assisting the plant to float. Leaves are thick and glossy, ovate. Flowers are attractive, lavender pink.
Distribution: Originally native to tropical South America. In the study area it was noted in Chukha (Logchina).

Impacts: It occupies ponds, lakes, paddy fields, and banks of slow running water bodies. Besides reproduction from seeds, it spreads by runners and stolons – stems. It can occupy stagnant water very fast affecting fishery, hinder navigation and choke running water bodies.

Management: When the cover is vast, chemical control is not effective and is environmentally damaging. Mechanical measures such as dredgers and shredders are used but can be costly. Biological control using weevils and other host specific insects are successfully tried. Early detection and eradication of this species is important to prevent its spread further.

Uses: Water hyacinth is useful in removing arsenic in water and can be useful in wastewater treatment. It is a good source of biomass and can be used in biogas production. The plants can be dried and used as fuel/firewood for cooking and heating. It is also used in composting and as animal fodder – which in excess can be toxic though. It is also used as a carotene-rich vegetable used in preparing salad and for cooking.

Fig. 1.12: *Pontederia crassipes* in flowers

1.3.13 Scientific name: *Trifolium repens*

Family: *Fabaceae*

Common names: Dutch clover, white clover.

Description: It is a short-lived perennial herb often forming mats over the ground. Stems have slender creeping stolon and are rooting at nodes. Leaves are trifoliate or divided into three lobes. Flowers are in a compact head, mostly white.

Distribution: Native to Europe and Central Asia. However, it has been introduced worldwide as fodder species. In the study area it was noted in Paro (Dokar) and Thimphu (Mewang).

Impacts: It grows well in open areas and can invade fallow agricultural land in the temperate region.

Management: While the plants can be easily weeded or uprooted, any stem segment left behind will grow again. Herbicides can be effective in areas with wide white clover cover. Applying nitrogen fertilizer can eliminate the plant. Clover root weevil can be used as biological control.

Uses: White clover is a good pasture plant and is also used as lawn cover. Flowers are excellent source of nectar for honeybees.

Fig. 1.13: *Trifolium repens* in flowers

SECTION II: EVALUATION OF COMMUNITY PERCEPTIONS AND MANAGEMENT OF IPS

2.0 Materials and Methods

To carry out household interview from the study sites, 30% of the total households from each village was sampled totalling up to 426 households. The questionnaire consisted of measuring socioeconomic features, demography, knowledge on IPS, impacts of IPS, management of IPS, and training requirements on IPS (Appendix 2.9).

2.1 Socioeconomic features of the respondents

This section presents the respondents' knowledge and perceptions of invasive species from the socio-economic point of view considering the effect on Ecosystem Services that supports the livelihood of the respondents in the study areas. The ecosystems represent sources of natural resources essential for the subsistence and socio-cultural continuity of rural society. This study assessed the status and ecological impacts of IPS on socio-economic aspects and biodiversity, and the mitigation measures and community management practices of the IPS in the identified study areas of the eight dzongkhags (Table 2.1). Therefore, this section briefly describes some of the impacts of invasive species as they form the basis for establishing proper management regimes.

A total of 426 households (Male 53.1% and Female 46.9%) were interviewed from the assigned study areas consisting of thirteen gewogs from eight dzongkhags (Table 2.1 and Appendix 2.6). The majority (31.22 %) of the respondents were from Samtse dzongkhag followed by Tsirang (18.78%) and Chukha (16.67%). The average household size is about eight persons with a maximum of forty-four and a minimum of one member registered in the same census. At the gewog level, Logchina under Chukha dzongkhag has a household size of 20.61 followed by Samtenling under Sarpang with 14.73 while Dophuchen under Samtse has the smallest with 2.39 persons. In all the gewogs, despite the relatively high average household size, absentee family members are common characteristic for all the households leading to the shortage of labour for agricultural activities.

Table 2.1: Dzongkhag wise respondents and gender

Dzongkhags	Gender		Total *n* (%)	Overall Percent
	Male *n* (%)	Female *n* (%)		
Chhukha	43 (60.56)	28 (39.4)	71 (100)	16.67
Dagana	25 (52.08)	23 (47.92)	48 (100)	11.27
Haa	19 (54.29)	16 (45.71)	35 (100)	8.22
Paro	13 (65.00)	7 (35.00)	20 (100)	4.69
Tsirang	38 (47.50)	42 (52.50)	80 (100)	18.78
Thimphu	2 (33.33)	4 (66.67)	6 (100)	1.41
Samtse	69 (51.88)	64 (48.12)	133 (100)	31.22
Sarpang	17 (51.52)	16 (48.48)	33 (100)	7.75
Total	226 (53.05)	200 (46.95)	426 (100)	100

2.2 Respondents' Demographic features

Regarding the age of the respondents, it is encouraging to find the majority (67.1%) in the young and active category between the age range of 18-50 years followed by 32.9% in 51 years and above (Table 2.2). Unlike some of the professions, farming is a physical activity where the age of the farmers is important from the labour as well as knowledge perspectives (young for the physical labour and older for the wisdom and knowledge). As commonly mentioned, agricultural knowledge and skills related to production, operation, and management, increase with age, which further help in enhancing the efficient use of agricultural inputs. In all the study areas, the inability to carry out agricultural activities is a common concern raised by those households with smaller family sizes and aging family members.

To assess and understand the respondents' education level, the education component was categorized as none, primary, secondary, diploma, undergraduate, and others. While the majority (65.7%) of the respondents were illiterate, it is impressive to find that about 26.8% of the respondents have attended formal education such as primary, secondary, diploma, and undergraduate level, a positive indication for the increase in the literacy rate of the farming community (Table 2.2). There are many reasons to believe that literacy and the educational status of people are important for the attainment of any social progress. For example, higher levels of education are expected to foster a healthy community environment like building higher social trust and reciprocity, better health and wellbeing, and an improved outlook towards the changes.

Table 2.2: Age and Education of the Respondents

No		Frequency	Percent (%)
Age range			
1	18–30	77	18.1
2	31-40	104	24.4
3	41-50	105	24.6
4	51-60	71	16.7
5	61 and above	69	16.2
Education level			
1	None	272	65.7
2	Primary	56	13.5
3	Secondary	48	11.6
4	Diploma	3	.7
5	Undergraduate	4	1.0
6	Others	31	7.5

Note: Education for 12 respondents were missing

The respondents in the other category (7.5%) have attended informal education like non-formal education (NFE), a few years of monkhood, and early school dropouts. For detail on dzongkhag wise male-female respondents, their age, and education level, refer to Appendix 2.1 and 2.2.

2.3 Respondents Knowledge of IPS

The assessment of the respondents' IPS knowledge level is important since it represents an important stakeholder in the management of IPS especially considering the impacts on cropping activities and their livelihood. The majority (97.7%) of the respondents were aware of the invasive plant species and their effects, especially on crop and livestock production activities. Some of the commonly mentioned invasive plant species include *Aegratina adenophora, Ageratum conyzoides*, *Chromolaena odorata*, *Mikania micrantha*, and *Parthenium hysterophorus*, which are seen to be a threat to the agroecosystems, water bodies, settlements, and roadsides in almost all the study areas. However, most respondents also refer to the invasive plant species to the seasonal weeds commonly grown in agricultural crops.

Knowledge of invasive plant species is important, as stated by many authors in ecological and ecosystem literature, 'what affects the ecosystems that we live in affects our daily lives as well'. Particularly for the farming community, invasive plant species is a concern since they can reduce crop yields, and many are toxic to livestock or harmful to human health.

As shown in Fig 2.1, although there is no strong association between the respondents' age and their knowledge about the IPS, a general trend can be observed where older respondents are relatively knowledgeable about the IPS compared to their younger counterparts.

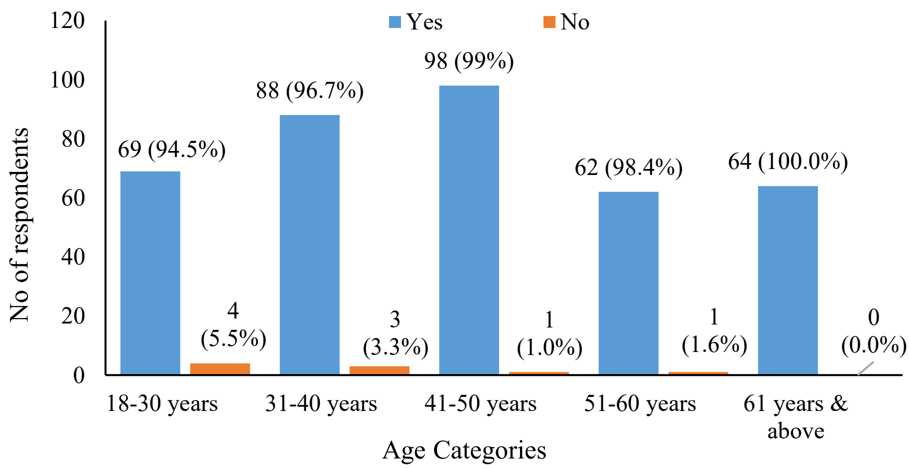

Fig. 2.1: Relation between respondents' age and knowledge on IPS

Similarly, there is little or weak positive association between respondents' education level and knowledge about IPS. Even the illiterate respondents are also equally knowledgeable and aware of the negative impacts of the invasive plant species.

2.4 Important weed species from the farmers' perspective

A list of invasive species analysed based on farmers' perspective using a MIC-MAC analysis ranking is provided in the Table 2.3. While the most important invasive alien species turns out to be *Ageratina adenophora* and *Mikania micrantha*, the third important invasive species is *Persicaria nepalensis* which is native species in the region. Two explanations are possible for this result. First, the farmers are not able to distinguish between what is native or exotic species. Secondly, since the study areas covered a wide eco-region – from the sub-tropical to temperate eco-region. So, what is abundant at lower altitude is not available at the higher altitude and vice versa. For similar reasons, the *Chromolaena odorata* has ranked 10th from among the 13 species analysed. About half of the species listed (seven out of thirteen) are native to the region. This is a clear indication that any species that affects agriculture practices and production is an invasive species from the farmers' perspective.

Table 2.3: Most important invasive alien species from farmers' perspectives

Species	5	4	3	2	1	MICMAC Sum	Rank
Ageratina adenophora	65	28	16	7	2	301024	1
Mikania micrantha	29	19	5	3	1	31401	2
Persicaria nepalensis	20	9	1	3	1	8758	3
Eleusine indica	19	11	8	2	0	8710	4
Ageratum conyzoides	16	14	12	5	2	8701	5
Bidens pilosa	16	13	10	7	4	7700	6
Cyperus cf. rotundus	16	9	1	3	1	4854	7
Cynodon dactylon	8	10	8	4	0	2088	8
Galinsoga parviflora	5	9	7	3	1	1225	9
Chromolaena odorata	2	7	7	6	1	911	10
Spermacoce cf. latifolia	1	2	7	0	0	352	11
Rumex nepalensis	2	4	0	4	0	136	12
Pteridium aquilinum	0	3	0	0	2	35	13

Note: 5=very high priority, 4=high priority, 3= medium priority, 2=low priority, 1=very low priority

2.5 Sources for IPS arrival

Invasive plant species (non-native) belong to another region of the world and usually arrive in the new environment through different means, and humans are regarded as the primary agent whether the introduction is intentional or accidental. To assess the respondents' perceptions, several potential sources or causes have been identified for the arrival of IPS in the study areas (Table 2.4). Based on the responses received from 377 (88.50%) respondents, about 53.05% expressed the import of animal feed and fodder as an important source, while 16.18% and 14.59% held plantation programs and transportation of goods responsible for the arrival of the invasive species in the study areas. For effective management and development of effective measures, it is important to identify and understand the potential sources and agents for the introduction of IPS.

Table 2.4: Sources and causes for the arrival of IPS in the locality

No	Sources	Frequency	Percent (%)
1	Ornamental	9	2.39
2	Plantations	61	16.18
3	Animal dispersal	20	5.31
4	Medicines	17	4.51
5	Arrived with seeds	15	3.98
6	Feeds & fodder	200	53.05
7	Transportation of goods	55	14.59

Note: 49 respondents have not provided any responses

Dorjee (2018) reported that around 1123 alien plant species have been introduced into the country as of 2018. He has identified the introduction pathway for more than 99.7% (n = 1120) of alien plants found in Bhutan brought as either ornamental (50%, n = 501), pasture (20%, n = 228), forestry (2.8%, n = 32) and agricultural sector (2%, n = 18). For example, the livestock sector introduced over 96% of the total pasture species recorded in Bhutan (n = 228) as of 2000. Similarly, since 1999 around 375 alien ornamental species have been introduced due to the growth of the ornamental sector.

2.6 Economic Value of IPS

While the invasive plant species have effects on several areas, the economic and social impacts include both direct and indirect effects on agriculture productivity, property values, and ecosystems. However, how they are valued particularly depends on the perceptions of the people at a given time and place, and the dimension of the impacts. Besides the negative impacts, invasive plants can also provide some economic and social benefits which the local communities could use for enhancing their livelihood. In the study areas, about 56% of the respondents are not aware of the economic value of the IPS. However, about 44% of the respondents expressed utilizing some of the IPS as herbs, fodder, and bedding for the livestock and mulching materials for the crops. However, they are unable to provide the monetary values for such use.

2.7 Problems caused by IPS

IPS can spread quickly and cause lots of damages to native habitats and local plant species, affecting water and soil quality, impacting human health, and escalating costs for control and mitigation efforts. Some of the effects of IPS include encroachment into agricultural land leading to loss of crop production and disease and shortage of fodder in livestock production. Assessing the IPS impact is challenging and imprecise as the full range of economic costs of biological invasions goes beyond the immediate impacts on the affected agricultural producers (Evans, 2003). Generally, the economic impacts of invasive are broadly categorized as direct and indirect impacts. However, the impacts or problems caused by the IPS in the current study were assessed based on the respondents' perceptions on reduction in agricultural production, increase in labour cost to control, negative effects on people's health, increase in soil erosion, reduction in water flow volume, the decline in plant species diversity, damage to infrastructure and negative impacts on natural scenery or aesthetic value (Fig 2.2).

Overall, most of the respondents (80.99%) perceive and strongly agree that IPS leads to a reduction in agricultural production, and similarly, 67.84% of the respondents reported that an increase in labour costs for IPS controls is a serious issue. Similarly, reduction of plant diversity, damage on infrastructure, and negative affect on aesthetics are quite significant if respondents stating strongly agree and agree are viewed together (Fig 2.2). On the other hand, many respondents remained neutral regarding the IPS effect on human health, soil erosion and a decrease in water flow by 47.78%, 47.18%, and 45.77% respectively.

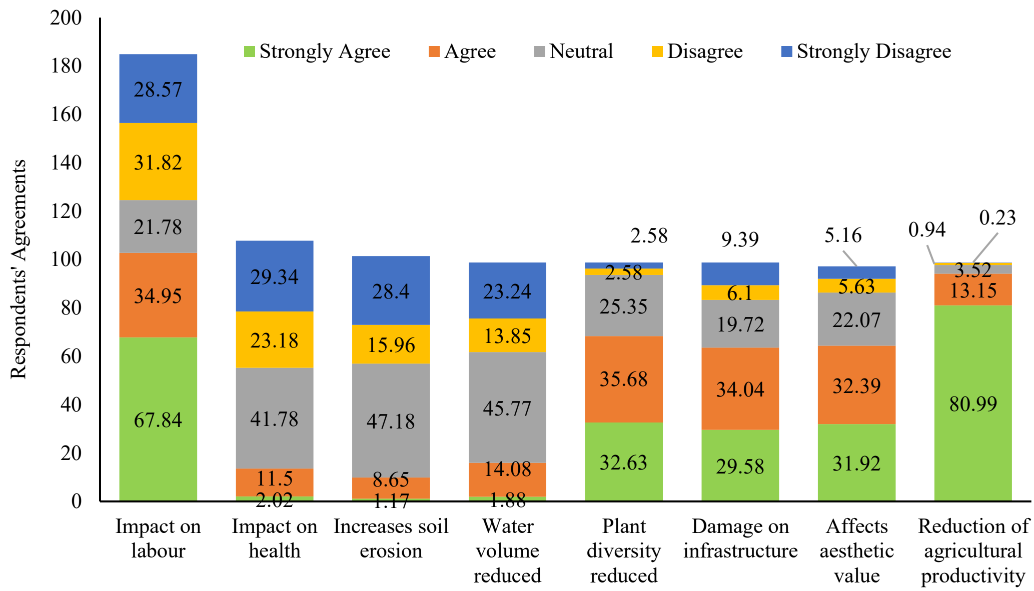

Fig. 2.2: Problems caused by IPS

2.8 Impacts at the ecosystem level

Invasive plant species can cause multiple effects in different areas. Therefore, all ecosystems are susceptible to invasion wherein forestry, agriculture fields and grazing lands are more susceptible to invasive species. In all the study areas, agriculture fields, fallow lands, settlements, and roadsides were highly susceptible to invasive species. For example, in Maedtabkha gewog under Chukha dzongkhag, Kikuyu (*P. clandestinum*) grass introduced as fodder has been reported to be problematic by spreading into the agriculture field, around homesteads, and roadsides. It is grazed by domestic cattle, horses, and goats but its uncontrollable spread has become worrisome particularly for the Eukha and Goenpa maed communities of the gewog.

2.9 Invasive species control methods

Considering the negative impacts of IPS, proper management is necessary to minimize the harmful effects of invasive species, especially on agricultural and livestock production, and for the protection of native plant species. Therefore, effective management of IPS is a priority for biological conservation worldwide (Kunwar and Acharya, 2013) and also for ensuring sustainable crop and livestock production in the study area. Since the respondents are aware of invasive plant species and their impacts, they rely on and use several IPS control measures. Among the control measures (Table 2.5 and Appendix 2.7), many of the respondents (93%) practice *manual* control measures, uprooting, digging, and burning. This is most effective if invasive plants are shallow-rooted, and the soil is loose or moist and minimum skills are involved and is often done along with the weeding of the crops. For example, respondents reported manual uprooting as effective and easy for *Ageratina adenophora* mainly due to its shallow rooting system while it is difficult and labour demanding for Kikuyu (*P. clandestinum*) grass. Control and management methods of some important IPS are shown in appendix 2.8.

Table 2.5: Respondents' IPS control measures

No	Control Measures	Frequency	Percent (%)
1	Manual control (uprooting and burning)	396	93
2	Mechanical control (Weeding, ploughing, hoeing)	63	14.8
3	Use of chemical	45	10.6

Mechanical control is another method adopted by 14.8% of the respondents, involving timely mowing or mechanical cutting of the IPS limiting the seed production and preventing further spread to other uninfected areas. For gewog wise refer Appendix 2.4. Although the use of chemicals for IPS control is not popular in the study areas, about 10.6% of the respondents have reported resorting to using at least once or twice to control invasive plants. The use of chemicals is said to be an effective measure especially for new and small infestations of invasive plants if proper precautions are taken to protect the non-target plants and environmentally sensitive areas. As the chemical control measures incur the cost and realizing the negative environmental impacts, the use of the chemicals is not an attractive option for the majority of the respondents in the study area. Besides the above control measures, it is also important to assess the potential for use of biological and cultural control measures by exploring and integrating rural indigenous knowledge.

2.10 IPS Management Measures

The invasive plant species can disrupt agriculture and natural ecosystems. As such development and adoption of appropriate control measures are necessary. Therefore, the study used public awareness on IPS, total removal, prevention to other areas, stricter regulations, early detection, surveillance, control, and eradication to assess the respondents' perceptions and choice for adoption as the IPS management measures in the study areas. In general, all the approaches, except doing nothing are rated very important or important measures for controlling the invasive species (Fig 2.3).

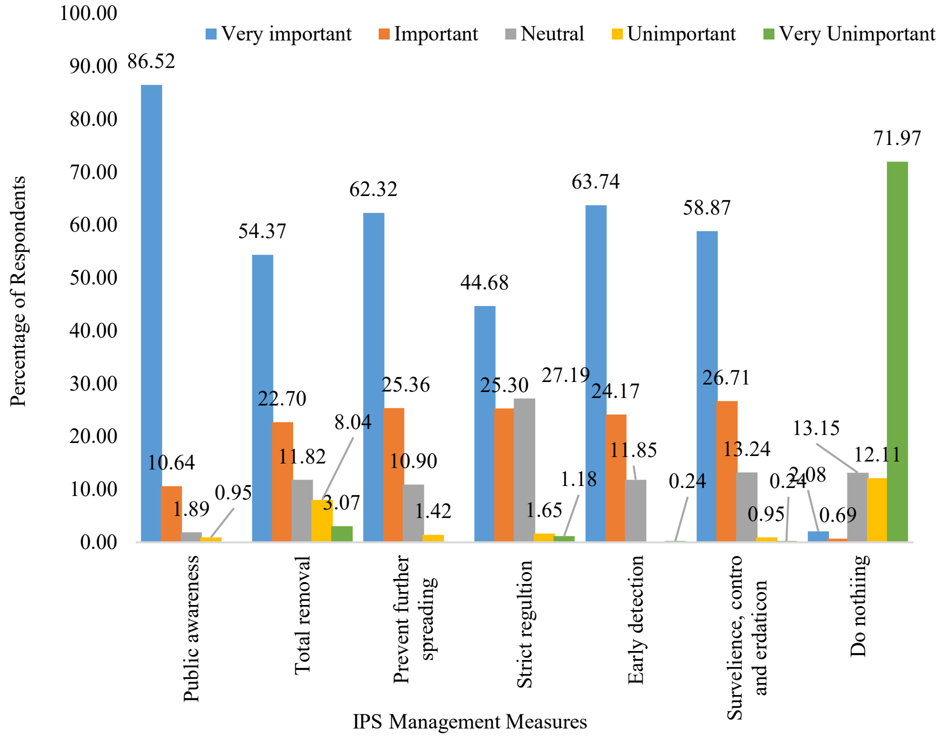

Fig 2.3: The management measures of invasive plant species- change the color of very unimportant, it is similar to very important

The majority of the respondents (97.16%) strongly agree that public awareness (education) on IPS is very important because what affects the ecosystems that people live in affects the daily lives of the people as well. Therefore, relevant training can help farmers to be well informed about the impacts and management aspects of invasive species. Moreover, public educational approaches can help improve farmers' knowledge and management, as reported by Yingzhen Li et al. (2021) where they explored the role of public education in farmers' knowledge and management of invasive *Mikania micrantha* in China.

Similarly, early detection and prevention from spreading to un-infested areas are also rated very important and important by 87.91% and 86.68% of the respondents respectively. According to Chris, Harte, and Chan (2009), exclusion and early detection are the most cost-effective methods of controlling and preventing IPS. Overall, the respondents in the study area are concerned about the spread and effective management of IPS because 71.91% of the respondents feel that doing nothing is not a solution to manage IPS.

According to Rejmanek et al. (2005) effective management of biological invasion should consist of three main steps: prevention, early detection, and eradication and control backed up by an integrated approach. They suggested that if prevention is no longer possible, treatment of infestations when they are immature is seen as essential to prevent them from establishing. Control measures are more effective in the least infested areas followed by consistent follow-up to ensure sustainable management. As mentioned by Kunwar and Ram (2013), the adoption of precise management measures for any IPS will depend upon factors such as institutional mechanism, policy structures, terrain, the cost and availability of labour, the severity of the infestation, and the presence of other invasive species. Further promotion of communities' participation through educational training and public awareness programs are seen as important processes for the control and prevention of the spread of invasive species.

As the IPS are the community's concern that demands collective action and effort management measures. About 80.7% of the respondents expressed the interest to form farmers' groups to combat the increasing problems caused by the invasive plant species on the crops, livestock, and homestead surroundings. The formation of farmers' groups looks viable considering the interest raised by the respondents and the presence of enabling policy supports today. However, the formation of groups should be pursued only after a thorough assessment of the necessary conditions and requirements.

2.11. Respondents' perceived IPS management skills

The study also assessed the requirement of IPS management skills at the farmers' level (Table 2.6). Nearly 50% of the respondents indicated that skills related to controlling the spread of IPS as the most important skill. The respondents ranked prevention skills (34.6%) as the second most important skill for managing the IPS. This is followed by skills related to impact reduction and finding the uses of IPS (28%) which is of equal importance to the respondents. The need for the various skills and knowledge expressed by the respondents in the study areas is mostly focused on the management of agricultural-related weeds and invasive species as they become a concern in crop production. For example, according to the respondents *A. adenophora* one of the most common invasive IPS in all the study areas invades into the agricultural field and competes with crops for fertilizer, water, sunlight, and space and causes serious crop losses and affects livestock production (Wan et al., 2010).

Table 2.6: Skills required as expressed by the respondents

No	Skills required on	Frequency	Percent (%)
1	Identification	70	26.9
2	Control measures	122	46.9
3	Prevention	90	34.6
4	Impact reduction	73	28.1
5	Finding uses	73	28.1

2.12 IPS and RNR Staff Knowledge

The respondents see the gewog RNR staff as an important source of knowledge and assistance in the effective management and control of weeds and invasive plants. As shown in Fig 2.4, prevention, identification, impacts, uses, and control measures on IPS were considered important knowledge areas that RNR staff must possess. Therefore, the majority (98%) of the respondents expressed that the RNR staff should be knowledgeable on the management of IPS. For example, about 28.05% of the respondents felt that the RNR staff should have better knowledge on IPS control measures and preventive knowledge by 23.49%. The farmers have high expectations from the RNR extension personnel in assisting the effective management of IPS, particularly in controlling and preventing it from spreading into the agricultural fields.

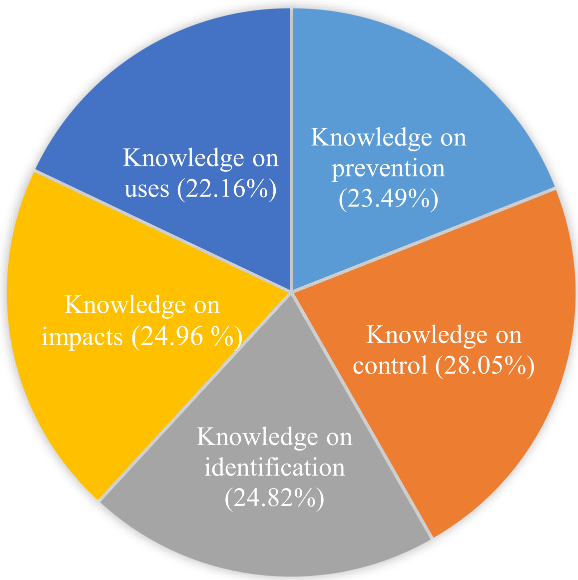

Fig 2.4. Knowledge requirement rating

The RNR field staff considering their academic background and job are the most relevant professionals that the farmers can approach and seek any assistance related to IPS management. In this respect, it is logical to explore ways to develop their capacity, especially in areas where they lack the expertise but are required to deliver as required by the farmers.

2.13 Respondents' Suggestions

Since the invasive weed species are expressed as nuisance for agricultural production especially in competing for nutrients with the crops leading to reduce crop yields, controlling invasive species is seen as necessary. Some of the suggestions from the respondents from all the study areas for effective management of IPS are summarized below:

- Make stricter laws and regulations for management, monitoring, and controlling to stop the introduction of new species.
- If possible, concerned authorities should provide chemicals and teach application methods.
- Organize farmers into groups (Farmers' Groups) to carry out mass management and cleaning of IPS.
- Provide public awareness training or education on IPS control and prevention measures like early detection, identification, and utilization for economic purposes
- Need budget support and expertise or professional advice on organic weed control measures.
- Try new species that can remove invasive species

SECTION III: MAPPING AND PREDICTION OF IPS

3.1 Data Collection

During the field survey, Invasive Plant Species (IPS) data were collected using the GPSMap 64s GARMIN GPS handheld units with the data collection form consisting of GPS ID, date, species code, elevation, aspect, scientific name, cover%, land use type, administrative units (dzongkhag, gewog, chiwog, and village). The occurrences of the IPS were recorded along the altitudinal gradients within the plot size of 4 x 4 m^2 at every study site using the opportunistic technique. Nineteen bioclimatic variables were downloaded from www.worldclim.org for the use in MaxEnt modelling. After removing the redundant variables from 19 variables, only Bio1 (annual mean temperature, Bio2 (mean diurnal range), Bio3 (Isothermality), Bio12 (annual precipitation), Bio14 (precipitation of driest month), Bio15 (precipitation seasonality), Bio16 (precipitation of wettest quarter), Bio17 (precipitation of wettest quarter), and Bio19 (precipitation of coldest quarter).

3.2 Database of IPS

The database for the species surveyed are organized with locational records (latitude and longitude), scientific name, date of recording, species code, habit (growth habit), elevation (elev), aspect, annual mean temperature (AMT), annual rainfall (APPT), cover% of the species record, land use/cover type, administrative units (dzongkhag, gewog, chiwog and village) and invasive index (Annex 3.1). Database will aid in data retrieval, manipulation, further analysis, and reporting in the future.

3.3. Geospatial Analysis methods

ArcGIS was used to analyse naturalization/establishment, invasiveness ranking, invasion index derivation and MaxEnt for spatial prediction. MaxEnt model provides spatial prediction from the species records samples and environmental variables such as bioclimatic variables derived from temperature and rainfall. Nineteen environmental variables were downloaded from the www.worldclim.org for the use in MaxEnt modelling.

3.3.1 Analysis of Naturalization and Successful Establishment

A general cover percent (NB: all species combined) was calculated to compare between different gewogs and ranked on a Likert scale of Very low, Low, Medium, High and Very high. Cover percent, an ocular estimate of IPS percent within the 4 x 4 m2 plot was used as an indicator of naturalization or successful establishment of IPS. Tading and Dorokha (Samtse) ranked highest followed by Logchina (Chukha), Laja (Dagana) and Samtenling (Sarpang) as shown in Fig 3.1.

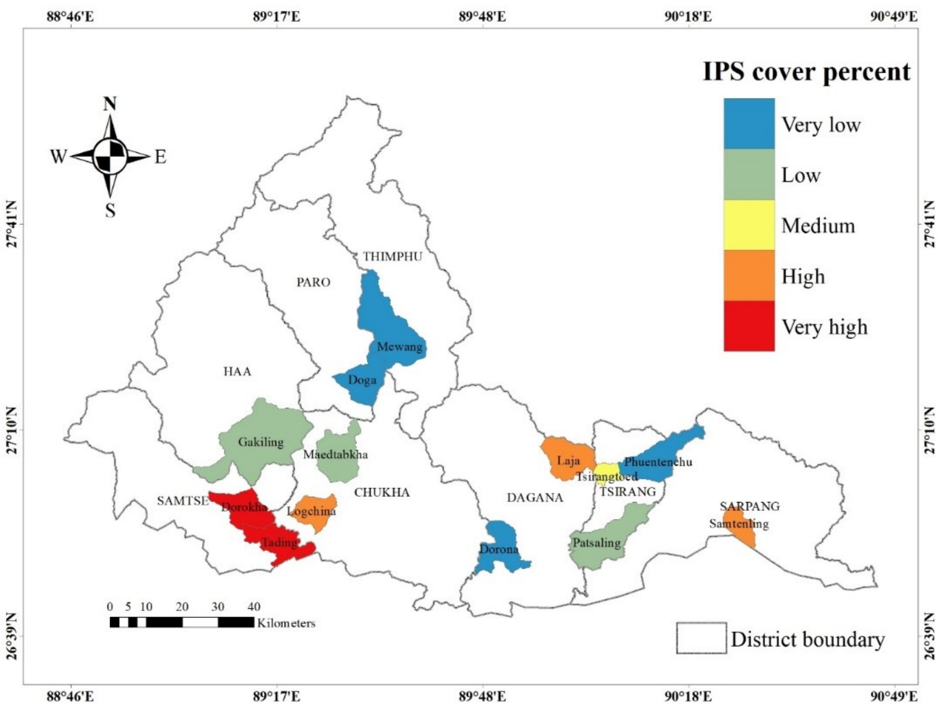

Fig 3.1: Cover percent by gewogs

3.3.2 Analysis of Invasiveness

Invasiveness ranking was analysed using parameters such as occurrence/observation frequency, land use diversity, latitudinal range, elevation range, number of slope direction[aspect], average cover% of observation, mean annual temperature range and annual rainfall range (Table 3.1) using the analysis of hierarchical process (AHP).

Table 3.1: Standardized Invasiveness ranking of IPS

Species	**Variables influencing invasiveness of species**								**Indicator**	
	X1	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**Index**	**Rank**
A. adenophora	1	0.86	1.68	0.59	1	0.11	0.34	1	6.57	1
B. pilosa	0.29	0.63	1	1	0.6	0.05	1	0.79	5.35	2
P. clandestinum	0.51	0.88	0.96	0.61	0.6	0.11	0.82	0.73	5.21	3
A. conyzoides	0.79	1	0.39	0.58	0.8	0.05	0.5	1	5.1	4
G. parviflora	0.16	0.5	1	0.97	0.4	0.04	0.93	0.78	4.77	5
T. repens	0.2	0.5	0.9	0.58	0.6	0.04	0.84	0.54	4.19	6
M. micrantha	0.34	0.63	0.39	0.47	0.8	0.09	0.49	0.96	4.17	7
C. odorata	0.4	0.75	0.39	0.52	0.6	0.09	0.49	0.61	3.87	8
C. crepidiodes	0.14	0.38	0.39	0.45	0.4	0.02	0.22	0.45	2.45	9
S. acuta	0.14	0.38	0.39	0.4	0.4	0.05	0.21	0.45	2.41	10
Spermacoce sp.	0.16	0.38	0.32	0.48	0.4	0.06	0.22	0.32	2.34	11
Syndrella sp.	0.09	0.38	0.38	0.47	0.2	0.05	0.17	0.44	2.17	12
P. hysterophorus	0.1	0.5	0.01	0.1	0.4	1	0.02	0.02	2.15	13
C. sativa	0.23	0.75	0.25	0.2	0.4	0.04	0.11	0.07	2.04	14
Persicaria nepalensis	0.07	0.25	0.32	0.17	0.6	0.04	0.11	0.31	1.87	15
T. officinale	0.1	0.5	0.25	0.21	0.4	0.04	0.13	0.07	1.69	16
C. album	0.11	0.5	0.25	0.21	0.2	0.04	0.1	0.06	1.48	17
T. minuta	0.1	0.5	0.25	0.23	0.2	0.02	0.1	0.06	1.47	18
D. stramonium	0.07	0.38	0.24	0.15	0.4	0.01	0.08	0.06	1.4	19
Cosmos sp.	0.07	0.13	0	0.01	0.2	0.01	0	0	0.42	20

X1=observation frequency; X2= number of land use type; X3=latitudinal range; X4=elevational range; X5=number of slope direction/aspect; X6=estimated ocular cover within the plot; X7=mean annual temperature range; X8=Annual rainfall range.

The factors X1 to X8 are the standardized (values from 0 to 1) indices to account for invasiveness of the species observed. X1 provides the quantity on frequency of observations (encounters) in the fields; X2 indicates how adaptable a given species is to different types of land use/cover. Higher the variety of land use the species are occurring in, higher the probability of the given species being invasive in nature. X3, X4, X7 and X8 provide range between maximum value and minimum value. Higher values indicate that the given species is tolerant to different environmental and climatic regimes and vice-versa. X5 provides suitable slope directions for the given species and more the number of slope directions that a species occurs in, more probable that species to be invasive in nature; X6 is to indicate the success of colonization of a species in each location. So higher the cover%, higher the colonization success. To derive the invasiveness index, the following equation was used:

$$\sum_{i=1}^{n} xi = x1 + x2 + \cdots + xn$$

Where *i* = index of summation; *n* = number of species; *x* = variables.

Table 3.1 shows the standardized values of each factor for each species. Index is the sum of all the factors for the species. *Ageratina adenophora* ranks (Rank = 1) the most invasive species while *Cosmos* is the least (Rank = 20) invasive plant.

3.3.3. Infestation dominance by growth habit of invasive plants on different land use types

By the cover percent, herb dominates infestations in all types of land use with the average cover percent of 72.82 (Table 3.2.). In addition to herbaceous IPS, Barren lands were more susceptible to shrubby IPS.

Table 3.2: Plant cover% by habit of growth

	Growth habit				
Land use types	**Climber**	**Grass**	**Herb**	**Shrub**	**Tree**
Barren land	12.50%	0%	75.00%	12.50%	0.00%
Cultivated Land	15.74%	0.43%	72.34%	11.49%	0.00%
Forest	17.93%	0%	70.34%	11.72%	0.00%
Roadside	18.06%	0%	73.61%	5.56%	2.78%
Average	16.06%	0.11%	72.82%	10.32%	0.69%

3.3.4. IPS Detection Frequency by Dzongkhag

Detection frequency of IPS is an indicator of invasion intensity and abundance in an area, thereby an area being exposed to invasion (Bayliss, et al., 2017). Dagana Dzongkhag had the most frequent detection of IPS followed by Chukha.

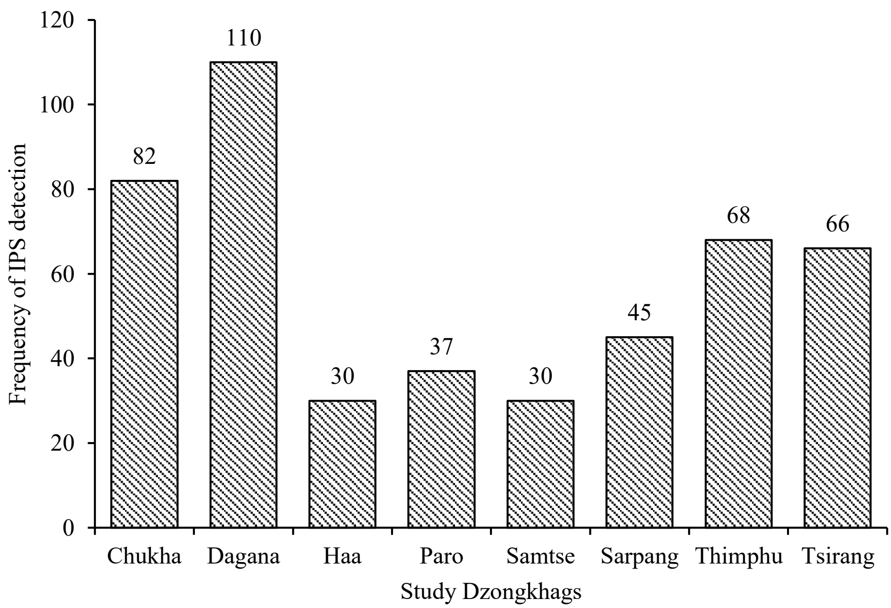

Fig. 3.2: Frequency of IPS detection by Dzongkhags

3.3.5 Diversity of IPS by Gewogs and Aspect

Diversity of IPS in an area suggests that the area is suitable for the establishment of different IPS, which is therefore an important parameter to measure susceptibility of a landscape to invasion. The highest IPS diversity was encountered in Dorona (16.03%) followed by Mewang (14.53%) and Maedabkha (13.46%) as shown Fig 3.3.

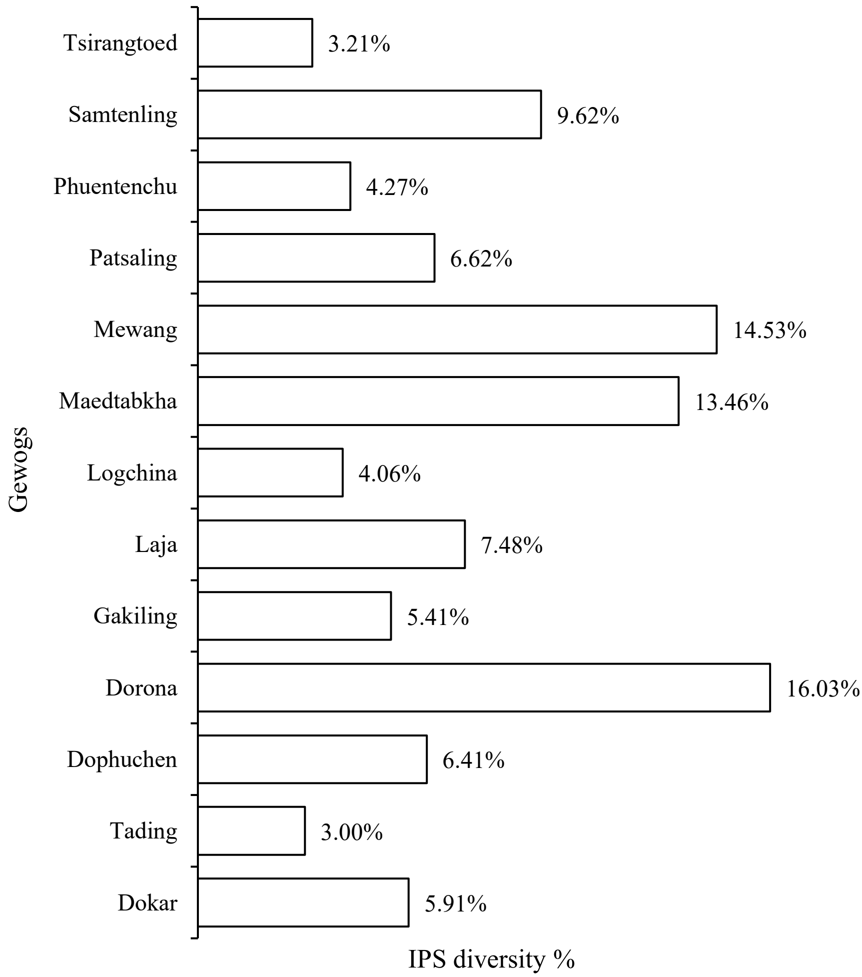

Fig. 3.3: IPS diversity by gewogs

Aspect is one of the determinants of growth condition of IPS. Some IPS may tolerate a variety of aspects for establishment while others may be restrictive to a single aspect. From Fig. 3.4, it is found that the top 6 IPS can grow in almost every aspect (except east and west), and south being the most preferred aspect especially by *A. adenophora* (n=37) and *A. conyzoides* (n=31), and exceptionally north being preferred by *P. clandestinum* (n=26).

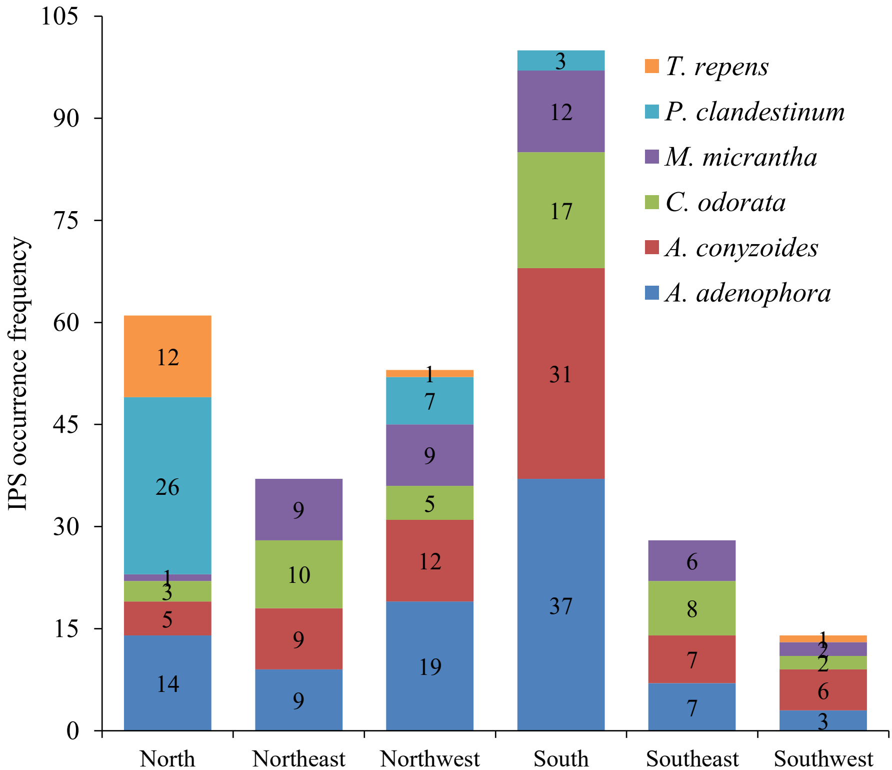

Fig 3.4: Aspects preferences by the invasive plants.

3.3.6 Analysis of Invasion Index for the Gewogs

The invasion index is an indicator of all the parameters that meet the criteria of hotspot and coldspot with statistically significant spatial clusters.

Hotspot indicates all the high values are clustered while the coldspot indicates all the low values are clustered.The hotspot based analysis of invasion index using the sum of cover percent, aspect diversity, land use diversity and habit diversity in ArcGIS showed the highest in Tading and Logchina, high in Maedtabkha, Dorokha, Dorona and Tsirangtoed with medium, low and very low in rest of the gewogs as shown in Fig. 3.5.

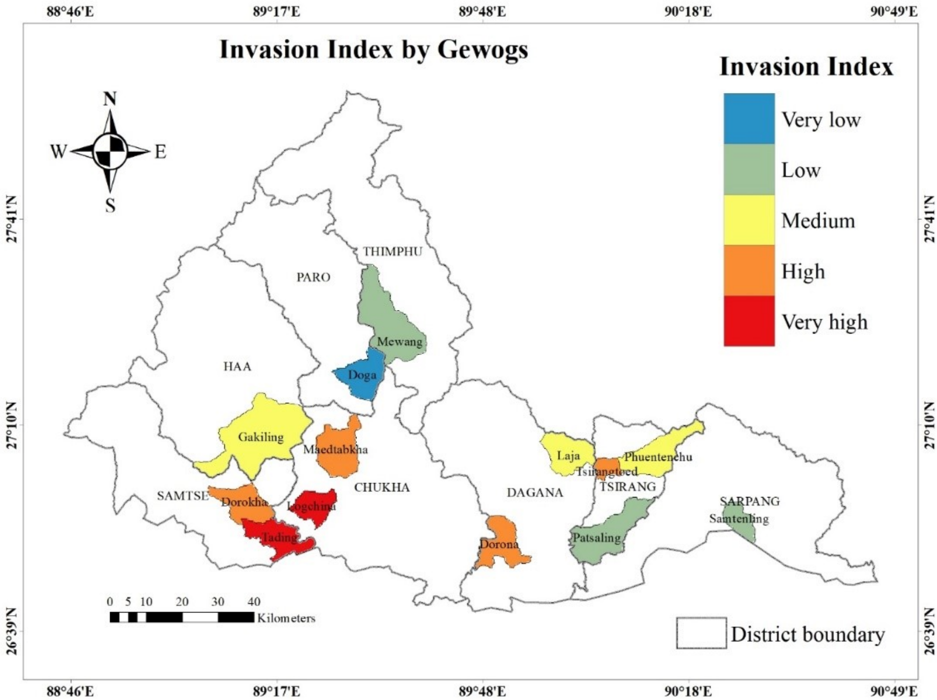

Fig. 3.5: Invasive index by gewogs

Where: Land use diversity = IPS located in more than one land use types (Cultivated land, Forest, barren land, roadside); Cover percent = Percent of IPS observed with other species within the plot size of 4m x 4m); Aspect diversity = IPS observed within eight cardinal directions of slope (North, Northeast, East, Southeast, South, Southwest, West and Northwest); Habit diversity = Herb, Shrub, Trees, Climbers, and Grass.

3.4 Spatial Prediction of Invasion by Major Invasive Plants

The habitat suitability for *Ageratina adenophora, Ageratum conyzoides, Chromolaena odorata, Mikania micrantha, Pennisetum clandestinum and Trifolium repens* were modelled using the Maximum Entropy algorithm, alias MaxEnt using the tenfold classification and cross-validation replication. The algorithm assumes that if the environmental conditions coincident to the target species are similar elsewhere within the study landscape, they are suitable for the species occurrence. The probability of suitability using the receiver operating characteristics (ROC) curve called area under the curve (AUC), zero being unsuitable and 1 being the most suitable. ROC is the measurement of relationship between the false positives along the x-axis and true positives along the y-axis, where false positives are wrong predictions of habitat suitability and true positives are right predictions. The first set of result is a probability map ranging from zero to one on a continuum scale (Fig. 3.6). Model prediction suggests that the suitability of invasion for *A. adenophora*, A. *conyzoides*, *C. ododrata* and *M. micrantha* are concentrated along the southern belt of study areas, while suitability extends to northern part of study areas for *P. clandestinum* and *T. repens*.

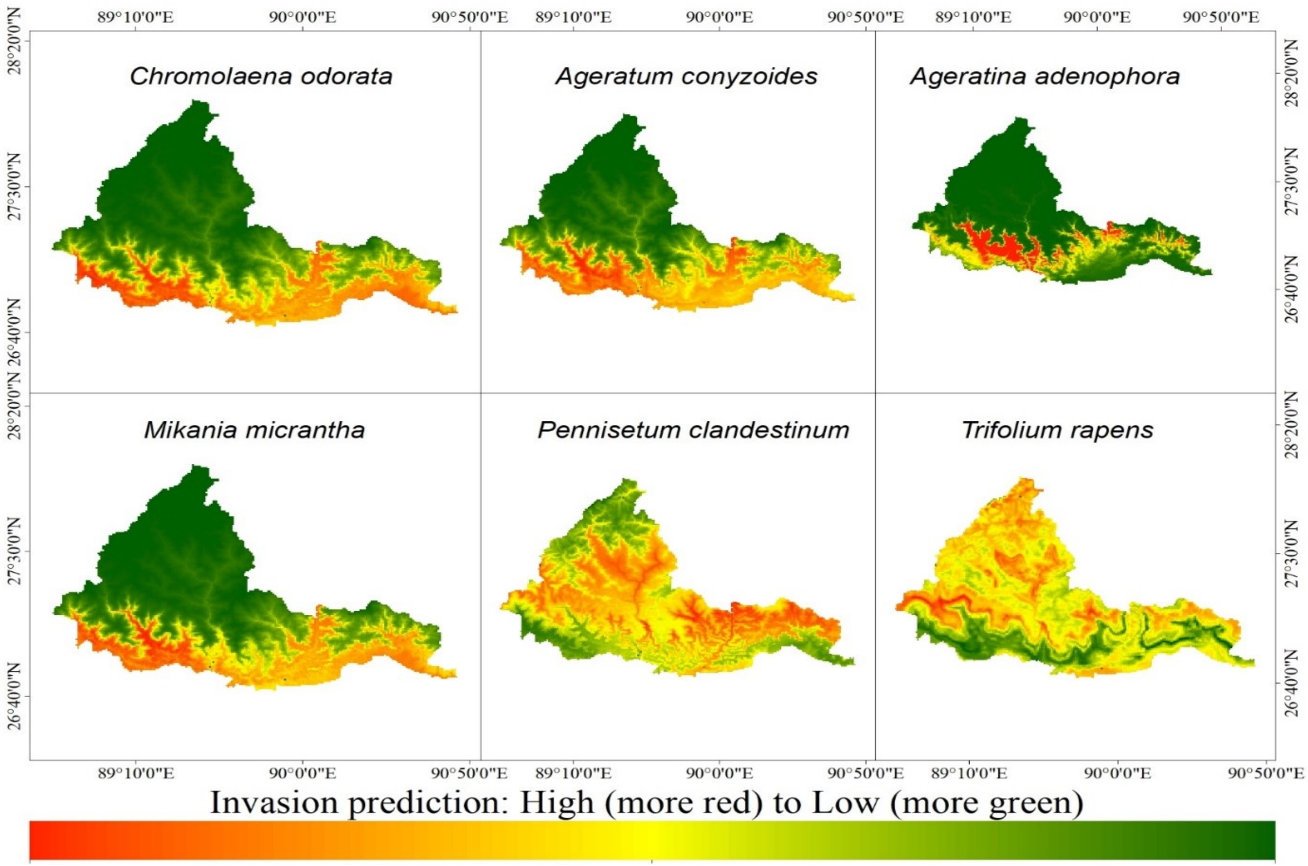

Fig. 3.6: Spatial Prediction of IPS distribution

The model performed better for *A. adenophora* (0.930 ± 0.053), and moderately for the rest of species (Table 3.3). According to spatial prediction, the invasion of *A. adenophora, A. conyzoides, C. odorata* and *M. micrantha* appears to remain along the southern belt, but invasion of *P. clandestinum* and *T. repens* seems to be much gregarious covering all the study Dzongkhags.

Table 3.3: Statistical output of MaxEnt Model with model setting

Species	Sample	Threshold rule	Accuracy of suitability (AUC ± SD)
A. adenophora	89	10 percentiles	0.930 ± 0.053
A. conyzoides	70	10 percentiles	0.817± 0.057
C. odorata	45	10 percentiles	0.836 ± 0.073
M. micrantha	39	10 percentiles	0.836 ± 0.061
P. clandestinum	36	10 percentiles	0.788 ± 0.116
T. repens	14	10 percentiles	0.793 ± 0.116

3.5 Presence and Absence Mapping

From the continuum (probability) prediction of invasion, binary prediction was mapped using the natural break threshold of reclassification tool in ArcGIS for each species (Fig 3.7). Binary prediction is essential for discretionary decision on presence or absence of invasion. Dagana had highest (17.37%) combined predicted percent presence of six species followed by Chukha (16.44%) and Samtse (16.32%) and Thimphu being lowest (4.60%) as shown in Fig. 3.8. Species wise versus Dzongkhag wise presence prediction in terms of area are shown in appendix 3.2.

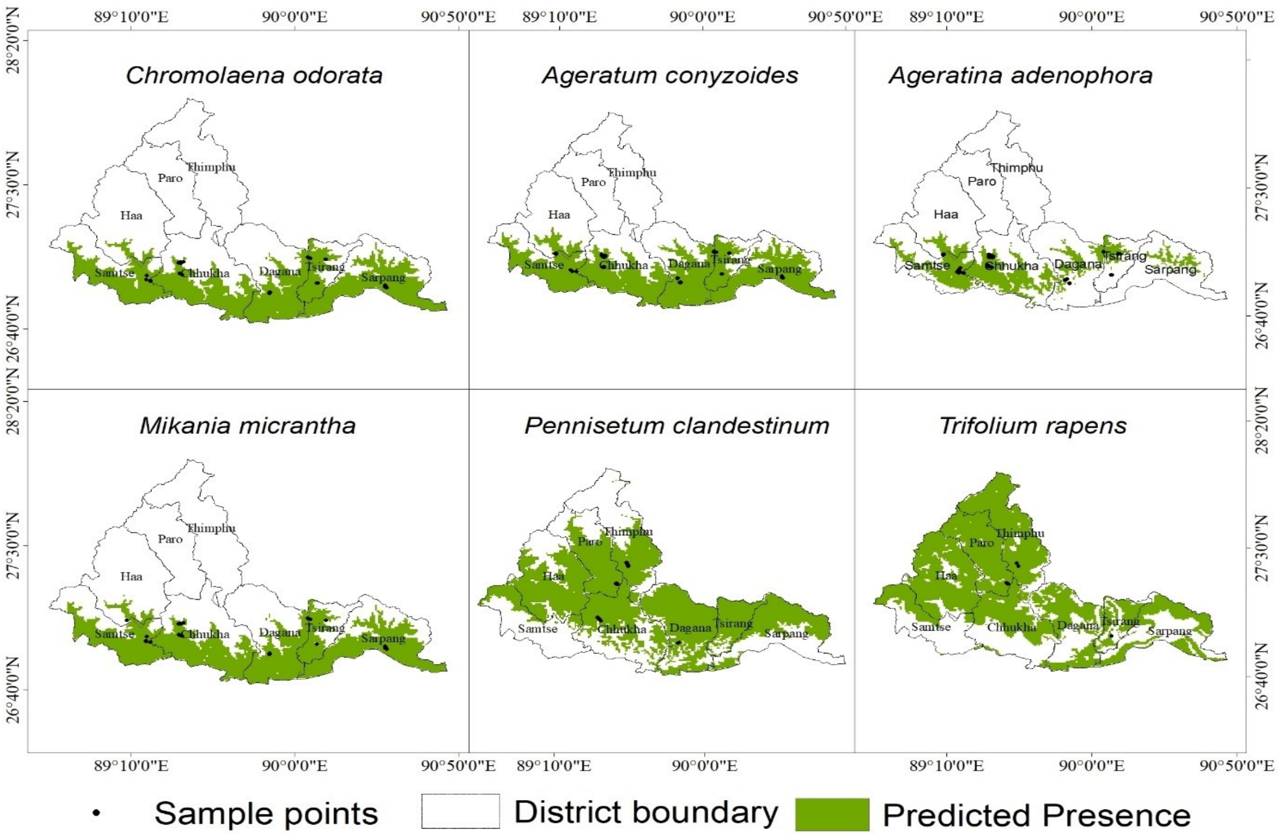

Fig. 3.7: Presence - absence map

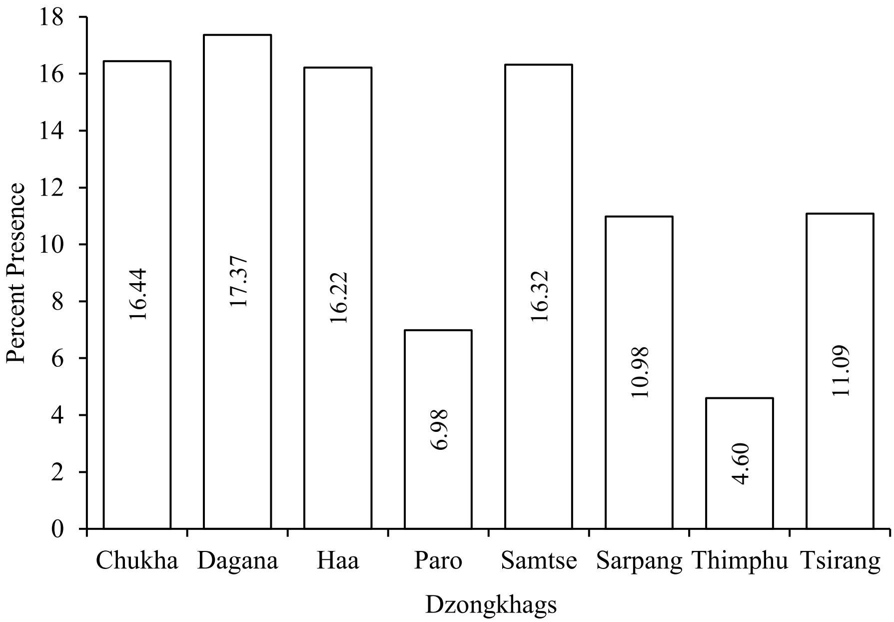

Fig. 3.8: Dzongkhag wise predicted presence of six IPS in percent

SECTION IV: CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions based on the lessons learned from the field and recommendations around socio-economic aspects of the study and findings from geospatial mapping and invasion prediction modelling.

4.1 Conclusions

All the study areas are in far-flung rural areas characterized by limited accessibility to other parts of the same or other Dzongkhags due to poor road conditions, especially in summer. The respondents as marginal farmers are seen to mainly practice subsistence crop-livestock mixed production systems. Most of the respondents are illiterate with an average household size of 7.8 persons. Regarding knowledge and awareness on IPS, only elderly people seem to be able to identify with local names and know about some traditional management techniques. But their knowledge too is restricted to weeds and IPS that grow in farmlands and around homesteads. Therefore, invasion by IPS still remains a critical concern in the study areas threatening the agroecosystem, environment, and the livelihood of the communities. For example, besides those well-known IPS, there are species such as *Pennisitum clandestinum* and *Trifoilum repens* are found to adapt to various ecoregions in the country according to the model prediction.

Among the sources of IPS arrival, the farmers feel that the primary sources are import of animal feed and fodder, plantation programmes and transportation of goods. Although these activities are initiated with the intention of benefiting communities, many respondents claim that IPS invasion leads to reduction in agricultural production and increase in labour costs since weeding frequency has increased after the arrival of agricultural weeds and IPS. As such, before initiating any activities that involve introduction of exotic plant species a thorough study of species is required by engaging relevant and competent stakeholders.

Control measures that the farmers practise are primarily manual (i.e., uprooting, cutting or burning) while some use mechanical methods such as ploughing and mowing, which they say are labour intensive.

Farmers appear to possess some superficial knowledge on utilizations of IPS, such as medicinal herbs, fodder, bedding for the livestock and mulching materials for the crops, but in-depth knowledge and techniques on using IPS for economic purposes are beyond their comprehension. Therefore, further exploration and enhancing farmers' knowledge on various utilizations of IPS with potential economic or commercial value can be a strategic approach to control the IPS. For instance, *A. adenophora and A. conyzoides* can be used as green compost, and *M. micrantha* can be used as fodder and as well as treating wounds.

Farmers, although feel the immediate impacts of invasion by IPS on their farms, they are not aware of long-term impacts such as environmental degradation in the form of biodiversity loss, decline in ecosystem services and climate change.

Among other types (shrub, grass, climber and tree), herbaceous IPS are found to occupy most of the study areas. They occupy almost all land use types- cultivated lands, barren lands, roadsides and forests. However, for climbers such as *M. micrantha*, and grass such as *P. clandestinum* equal priority is suggested. *M. micrantha* was found to damage different orchards and *P. clandestinum* was predicted as most gregarious IPS by the model.

4.2 Recommendations

There are three sets of recommendations- the short-, medium- and long-terms. Short recommendations are for immediate follow-up actions, while medium-term recommendations can be implemented one or two years from the day of this report submission. Long-term recommendations are legislative in nature which may call for future strategies, longer dialogues and discussions at different levels of legislative body.

4.2.1 Short-term recommendations

Focus on gewogs that were ranked highest in invasive index mapping (Fig. 3.5) and IPS that were ranked by farmers using MICMAC Sum analysis (Table 2.3). *Ageratina adenophora* ranked the highest by the farmers and Standardized Invasiveness Ranking (Table 3.1). For individual IPS control methods, refer Species Description under section I and Seasonal Calendar in the field manual of this report.

Immediate control measures for the established and naturalized IPS, manual removal (uprooting, burying in the pit or burning) can be cost-effective when found around homestead and in small patches. However, if the spread of IPS has escaped to a wider range, farmers may apply mechanical and chemical techniques of control.

Farmers should be advised on early detection of IPS using the seasonal calendar (refer field manual) which prescribes the months on detection and specific control techniques.

Tarayana Foundation field officers and RNR staff should provide technical advice on removing *Mikania micrantha* since this species was found to severely damage horticultural crops, particularly orange orchard.

Field officer of Tarayana Foundation should possess some plant identification applications that can be installed on smartphones (refer field manual). However, the identity of the plant should be confirmed with botany experts or taxonomist.

Follow the calendar of IPS growing season particularly flowering season to enhance detection and prevention of seed dispersal (refer field manual). Frequency of detection by Dzongkhag (Fig 3.2) and diversity percent of IPS by gewogs (Fig. 3.3) can guide in prioritizing implementation of control measures.

Since this report only did spatial prediction on few species, Tarayana Foundation programme coordinator can do the same for remaining species using the species occurrence record (with georeferenced locations) and environmental datasets (bioclimatic variables, consisting of both present and future scenarios) that are submitted in digital format to the office.

4.2.1 Medium-term recommendations

Field officer of the Tarayana Foundation should work in close consultation with Forestry, Livestock and Agriculture field staff. Forestry staff are supposed to identify IPS, while Livestock staff can advise on how to manage fodder plants and Agriculture staff can advise on agricultural weed management.

Training of communities should be conducted on an integrated or a joint basis, i.e., all the RNR staff and TF field officer to have wholistic ideas put together.

As expected by the farmers, RNR staff should undergo a tailor-made training on identification, prevention and control of IPS.

Organizing/observing an annual event as IPS Prevention and Control Day is suggested. During the day the officials can raise awareness on the cost and harmful/useful effects of IPS.

IPS vigilante team should be constituted with the team consisting of a chair at the gewog level and members from each chiwog or village. This team will regulate the import of alien plants be it in the form of seeds, seedlings or any other forms that will later lead to propagation (e.g., ornamental, soil conservation, fodder plants etc.).

Mainstreaming of a reporting system on arrival of any new alien plants be done annually by the vigilante team members on annual basis as early detection and warning system.

4.2.2 Long-term recommendations

For agricultural weeds, it is advisable that farmers follow the integrated pest management (IPM). IPM is a four tiered approach: (i) Setting Action Thresholds- a point when it is thought that pest population and environment indicate pest control action must be conducted or the level when pests become an economic threat; (ii) Monitoring and identification- accurate identification can lead to appropriate control decisions in conjunction with action thresholds, thereby removing the possibility of using pesticides; (iii) Prevention- in an agricultural crop, this can be using cultural methods (e.g., rotating between different crops, selecting pest-resistant varieties, and planting pest-free rootstock); (iv) Control- when monitoring, identification, and action thresholds indicate requirement of pest control and preventive methods are no more effective, then select highly targeted chemicals or mechanical control.

All alien plants, unless ecological characteristics are not invasive, should be prohibited from import or cultivation be it in private- or state-owned lands.

If at all necessary, by the economic or conservation values, the plants should be cultivated on a pilot basis for three to five years.

Local bylaws can be formulated within the purview of national laws pertaining to invasive alien species, which can embody prohibition of plant trafficking and cultivation of alien plants that are not tested within the country.

Local government statute on prevention and control of IPS maybe legislated using the grassroot participation in decision making.

Tarayana Foundation may propose legislations in collaboration with relevant agencies such as National Environment Commission, National Biodiversity Centre and Plant Protection Division, Ministry of Agriculture and Forest.

Periodically review national and regional policies and procedures on biosecurity, risk assessment, trade, movement, holding, release into the environment, establishment, and management of invasive plant species, revise to bring up to international standards and best practice, and harmonise across the country.

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Appendices

Appendix 2.1: Dzongkhag wise gender and age structure of the respondents

Dzongkhag	No and %	Gender		Total	Age structure of respondents					Total
		Male	Female		18-30	31-40	41-50	51-60	61 & above	
Chukha	No % within Dzongkhag	43 (60.6%)	28 (39.4%)	71 (100%)	18 (25.4%)	22 (31.0%)	10 (14.1%)	9 (12.7%)	12 (16.9%)	71 (100%)
Dagana	No % within Dzongkhag	25 (52.1%)	23 (47.9)	48 (100%)	8 (16.7%)	12 (25.0%)	13 (27.1%)	6 (12.5%)	9 (18.8%)	48 (100%)
Haa	No % within Dzongkhag	19 (54.3%)	16 (45.7%)	35 (100%)	7 (20.0%)	13 (37.1%)	3 (8.6%)	4 (11.4%)	8 (22.9%)	35 (100%)
Paro	No % within Dzongkhag	13 (65.0%)	7 (35.0%)	20 (100%)	3 (15.0%	3 (15.0%)	7 (35.0%)	4 (20.0%)	3 (15.0%)	20 (100%)
Tsirang	No % within Dzongkhag	38 (47.5%)	42 (52.5%)	80 (100%)	13 (16.25%)	13 (16.25%)	22 (27.5%)	13 (16.25%)	19 (23.5%)	80 (100%)
Thimphu	No % within Dzongkhag	2 (33.3%)	4 (66.7%)	6 (100%)	0	2 (33.3%)	1 (16.7)	2 (33.3%)	1 (16.7%)	6 (100%)
Sarpang	No % within Dzongkhag	17 (51.52%)	16 (48.48%)	33 (100%)	5 (15.20%)	5 (15.20%)	11 (33.3%)	9 (27.3%)	3 (9.10%)	33 (100%)
Samtse	No % within Dzongkhag	69 (51.88%)	64 (48.12%)	133 (100%)	24 (19.5%)	28 (22.80%)	34 (27.6%)	23 (18.7%)	14 (11.4%)	133 (100.00)%
Total	No % within Dzongkhag	226 (53.05%)	200 (46.95%)	426 (100%)	78 (18.8%)	97 (23.4%)	100 (24.2%)	70 (16.9%)	69 (16.7%)	41 (100%)

Appendix 2.2: Dzongkhag wise Respondents' Education Level

Dzongkhags	**No and %**	**Education level**						**Total**
		None	Primary	Secondary	Diploma	Graduate	Others	
Chukha	No % within Dzongkhag	43 (60.6%)	12 (16.9%)	12 (16.9%)	2 (2.8%)	0 (0%)	2 (2.8%)	71 (100%)
Dagana	No % within Dzongkhag	30 62.5%	6 (12.5%)	6 (12.5%)	0 (0%)	1 (2.1%)	5 (10.4%)	48 (100%)
Haa	No % within Dzongkhag	25 (71.4%)	3 (8.6%)	3 (8.6%)	0 (0%)	0 (0%)	4 (11.4%)	35 (100%)
Paro	No % within Dzongkhag	8 (42.1%)	2 (10.5%)	3 (15.8%)	0. (0%)	0 (0%)	6 (31.6%)	19 (100%)
Tsirang	No % within Dzongkhag	51 (63.8%)	7 (8.8%)	20 (25.0%)	0. (0%)	0. (0%)	2 (2.5%)	80 (100%)
Thimphu	No % within Dzongkhag	3 (50.0%)	1 (16.7%)	0. (0%)	0. (0%)	2 (33.3%)	0. (0%)	6 (100%)
Sarpang	No % within Dzongkhag	21 (63.6%)	5 (15.20%)	1 (3.0%)	1 (3.0%)	0 (0.0%)	5 (15.2%)	33 (100%)
Samtse	No % within Dzongkhag	91 (74.6%)	20 (16.40%)	3 (2.50%)	0 (0.00%)	1 (0.8%)	7 (5.7%)	122 (100%)
Total	No % within Dzongkhag	272 (65.7%)	56 (13.50%)	48 (11.6%)	3 (0.7%)	4 (1.0%)	31 (7.50%)	414 (100%)

Appendix 2.3: Respondents' education level and IPS knowledge

Education level	**Number of responses and percentage**			**Total**
		Yes	No	
None	No % within Education level	249 (98.80%)	3 (1.20%)	252 (100.00%)
	% of Total	(63.52%)	(0.80%)	(64.30%)
Primary	No % within Education level	53 (98.10%)	1 (1.90%)	54 (100.00%)
	% of Total	(13.52%)	(0.30%)	(13.80%)
Secondary	No % within Education level	46 (95.80%)	2 (4.20%)	48 (100.00%)
	% of Total	(11.73%)	(0.50%)	(12.20%)
Diploma	No % within Education level	3 (0.78%)	00 (0.00%)	3 (100.00%)
	% of Total	(0.77%)	(0.00%)	(0.80%)
Graduate	No % within Education level	4 100.00%	0 (0.00%)	4 (100.00%)
	% of Total	(1.02%)	(0.00%)	(1.00%)
Others	No % within Education level	28 (90.30%)	3 (9.70%)	31 (100.00%)

	% of Total	(7.14%)	(0.80%)	(7.90%)
Total	No % within Education level	383 (97.70%)	9 (2.30%)	392 (100.00%)

Appendix 2.4: IPS management measures

No	Management Measures	Very important	Important	Neutral	Unimportant	Very Unimportant
1	Public awareness	366 (86.52%)	45 (10.64%)	8 (1.89%)	4 (0.95%)	0.00
2	Total removal	230 (54.37%)	96 (22.70%)	50 (11.82%)	34 (8.40%)	13 (3.07%)
3	Prevent further spreading	263 (62.32%)	107 (25.36%)	46 (10.90%)	6 (1.42%)	0.00
4	Strict regulation	189 (44.68%)	107 (25.30%)	115 (27.19%)	7 (1.65%)	5 (1.8%)
5	Early detection	269 (63.74%)	102 (24.17%)	50 (11.85%)	0.00	1(0.2%)
6	Surveillance, control, and eradication	249 (58.9%)	113 (26.7%)	56 (13.2%)	4 (0.9%)	1 (0.24%)
7	Do nothing	6 (2.08%)	2 (0.69%)	38 (13.15%)	35 (12.11%)	208 (71.97%)

Appendix 2.5: Gewog wise household size of the respondent*s*

No	Gewogs	Dzongkhags	No of Households	Total Household members	Average family size respondents
1	Logchina	Chukha	36	742	20.61
2	Metakha	Chukha	35	304	8.69
3	Dorona	Dagana	40	330	8.33
4	Lajaab	Dagana	8	51	6.38
5	Gakiling	Haa	35	261	7.46
6	Dokar	Paro	20	178	8.90
7	Patshaling	Tsirang	20	155	7.75
8	Phuentenchu	Tsirang	22	194	8.82
9	Tsirangtoed	Tsirang	38	353	9.29
10	Mewang	Thimphu	6	39	6.80
11	Dophuchen	Samtse	67	160	2.39
12	Tading	Samtse	66	282	4.41
13	Samtenling	Sarpang	33	486	14.73
14	Total		426	3535	8.30

Appendix 2.6: Gewog wise Male and Female respondents

No	Gewogs	Dzongkhags	Male	Female	Total
1	Logchina	Chukha	24	12	36
2	Metakha	Chukha	19	16	35
3	Dorona	Dagana	21	19	40
4	Lajaab	Dagana	4	4	8
5	Gakiling	Haa	19	16	35
6	Dokar	Paro	13	7	20
7	Patshaling	Tsirang	8	12	20
8	Phuentenchu	Tsirang	11	11	22
9	Tsirangtoed	Tsirang	19	19	38
10	Mewang	Thimphu	2	4	6
11	Dophuchen	Samtse	20	41	67
12	Tading	Samtse	43	23	66
13	Samtenling	Sarpang	17	16	33
14	Total		226	200	426

Appendix 2.7: Gewog wise use of IPS control methods

Gewogs	Total Respondents	Manual control	Mechanical control	Chemical control
Logchina	36	36 (100%)	20 (56%)	4 (11.1%)
Metakha	35	34 (97%)	4 (11%)	0
Dorona	40	36 (90%0	11(28%)	0
Lajab	8	8 (100%)	2 (25%)	0
Gakiling	35	34 (97%)	5 (14%)	0
Dokar	20	20 (100%)	4 (20%)	3 (15%)
Patshaling	20	20 (100%)	2 (10%)	0
Phuentenchu	22	22 (100%	2 (9%)	2 (9.09%)
Tsirangtoed	38	36 (95%)	7 (18%)	3(7.89%)
Mewang	6	6 (100%)	1 (17%)	1(16.67%)
Dophuchen	67	57 (85%)	2 (3%)	8 (11.94%)
Tading	66	56 (85%)	1(2%)	22 (33.33%)
Samtenling	33	31(94%)	2 (6%)	1(3.03%)
Total	426	396 (93%)	58 (14%)	44 (10.33%)

Appendix 2.8: Control and management of important invasive

Species	Manual	Chemical	Biological	Cultural	Mechanical
Ageratina adenophora	☐	☐	☐	☐	
Mikenia micrantha	☐	☐	☐		☐
Persicaria nepalensis	☐	☐		☐	☐
Eleusine cf. indica	☐	☐			
Ageratum conyzoides	☐	☐			☐
Bidens pilosa	☐	☐			☐
Cyperus cf. rotundus	☐	☐			
Cynodon dactylon	☐	☐			
Galinsoga parviflora	☐	☐		☐	☐
Chromolaena odorata	☐	☐	☐		
Spermacoce cf. latifolia	☐	☐		☐	☐
Rumex nepalensis	☐				☐
Pteridium aquilinum	☐				☐
Cultural = maintaining spacing, selection of superior varieties etc					
Mechanical = using machine, tillage etc.					
Manual = weeding, uprooting, cutting etc. that consume use of labour					
Biological = using biological agents such as insects					
Chemical = using weedicide/herbicides					

Appendix 2.9: Household Survey Questionnaires for Invasive Plant Species

1. BACKGROUND INFORMATION

a) Dzongkhag: ………………b) Gewog: ……………c) Chiwog: …………..d) Village…

2 SOCIOECONOMIC INFORMATION

2.1 Sex: a) Male ☐ b) Female ☐

2.2 Age

a) 18-30 ☐ b) 31-40 ☐ c) 41-50 ☐ d) 51-60 ☐ e) > 60 ☐

2.3 Highest level of formal education attained.

a) None ☐ b) Primary ☐ c) Secondary ☐ d) Diploma ☐

e) University graduate ☐ f) Others ☐ (Specify)……………………………….…………

2.4 Household size: ……………………………………………………………………………

3. KNOWLEDGE ON IPS

3.1 Do you know what an invasive plant is?

a) Yes ☐ b) No ☐

3.2 If yes, mention invasive plant species in your locality with the approximate year of arrival

No	Invasive Plant Species	Year of arrival
1	E.g. Parthenium	
2		
3		
4		
5		

1 - 5 years = 1; 6 - 10 years = 2; 11-15 years = 3; 16 - 20 years = 4; >20 years = 5

3.3 How do you think the invasive plant species have arrived in your locality?

No.	Species	Source
1		
2		
3		
4		
5		
6		
7		
8		
9	Others (specify)……………………	

1= ornamental; 2 = plantations; 3 = animal dispersal; 4 = medicines; 5 = mixed in seeds; 6 = feeds & fodder; 7 = transportation; 8 = Do not know; 9 = others

3.4 The problems caused by invasive plant species are:

No.	Effects of Invasive Plant Species	1	2	3	4	5
1	Reduction in agricultural production					
2	Increase in labour cost to control IPs					
3	Negative effects on people's health					
4	Increase in soil erosion					
5	Reduction in water flow volume					
6	Decline in plant species diversity					
7	Damage to infrastructure					
8	Negative impacts on natural scenery					
9	Others (specify)……………………					

1 = Strongly Agree; 2 = Agree; 3= Neutral; 4 = Disagree; 5 = Strongly Disagree

3.5 Mention ONE worst effect that invasive plant species caused in your area.

…………………………………………………………………………
…………………………………………………………………………
…………………………………………………………………………

3.6 Rank FIVE invasive plant species in order of their impacts in your locality.

Rank	Invasive Plant Species
1	
2	
3	
4	
5	

1 = Very negative; 2 = Negative; 3 = Neutral; 4 = Positive; 5 = Very Positive

4. AWARENESS AND CONCERN

4.1 Do you think IPS is an important issue?

Yes ☐ b) No ☐

4.2 Why?

………………………………………………………………………………

………………………………………………………………………………

4.3 The invasive plant species over the years has

No	Invasive plant species	1	2	3	4	5
1						
2						
3						
4						
5						

1= significantly increased; 2 = increased; 3 = remained same; 4=Decreased; 5= Don't know

4.7 Are you aware that the uncontrolled spread of IPS may be dangerous for agriculture?

a) Yes ☐ b) No ☐

4.8 If Yes, why?

……………………………………………………………………………
……………………………………………………………………………
……………………………………………………………………………

5. AVAILABILITY OF INFORMATION

5.1 Do you feel you are adequately informed about invasive plants?

Yes ☐ b) No ☐

5.2 If Yes, on what aspects of IAPS? (*Can answer more than ONE*)

a) Identification ☐ b) Control measures ☐

c) Prevention ☐ d) Impacts ☐ e) Uses ☐

5.3 If No, what information on IAPS are important to be known by you? (*Can answer more than ONE)*

a) Identification ☐ b) Control measures ☐

c) Prevention ☐ d) Impacts ☐ e) Uses ☐

5.4 Do you think the RNR Staff should be knowledgeable about invasive plant species?

Yes ☐ b) No ☐

5.5 If yes, in what areas should they be knowledgeable? *(Can answer more than ONE)*

a) Prevention ☐ b) Control ☐ c) Identification ☐ d) Impacts ☐

e) Uses ☐

6. MANAGEMENT SOLUTIONS

6.1 How do you manage or control the Invasive plant species? *(Can answer more than ONE*)

a) Manually ☐ b) Chemically ☐ c) Mechanically ☐

d) Culturally ☐

6.2 Which method is more effective?

No	Species	Manual	Chemical	Mechanical	Cultural	Annual Costs (Nu)
1						
2						
3						
4						
5						

Very Effective (1); Effective (2); Neutral (3); Not Effective (4); Not at All (5)

6.3 Why is the method more effective than others?

……………………………………………………………………………
……………………………………………………………………………

6.4 What do you think is the best way to manage invasive plant species?

No.	Management measures	VI	I	N	UI	VU
1	Public awareness					
2	Total removal					

3	Prevent entry to un-infested areas					
4	Stricter regulations					
5	Early detection					
6	Surveillance, control and eradication					
7	Do nothing					

VI = Very important (1); I= Important (2), N= Neutral (3), UI= Unimportant (4); VU= Very Unimportant (5).

6.5 Choose ONE from Table 6.4 that you would adopt voluntarily as a measure to reduce the risk of invasion.

…………………………………………………………………………………

…………………………………………………………………………………

6.6 Do you think management of IPs should be regulated by legislation?

Yes ☐ b) No ☐

6.7 If yes, what rules and regulations would you recommend for effective prevention and control of IPs?

…………………………………………………………………………………

…………………………………………………………………………………

6.8 Is it possible to eradicate Invasive Species?

a) Yes ☐ b) No ☐

6.9 Would you form a group to manage invasive plant species?

a) Yes ☐ b) No ☐

6.10 If yes, what clauses will you incorporate as by-laws of the groups?

1: ……………………………………………………………………………………

2: …………………………………………………………………...……………

3: …………………………………………………………………...……………

4: …………………………………………………………………...……………

7. ECONOMIC VALUE

7.1 List IAPs with their economic value

No	Invasive plant species	Economic value/uses
1		
2		
3		
4		

7.2 If IPS is of economic value, will you introduce a new species in your area?

Yes ☐ b) No ☐

7.3 Any suggestions for improving management, control or monitoring of invasive alien plant species in your locality?

……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

Enumerator: …………………….………………………………………..

Date: ……………../………………/……….…………..

Approval signature: ………………………….…………………………..

Appendix 3.1: Snippet of the IPS database (note: full data in digital format)

Dzg	Gewog	Chiwog	Village	Date	Species code	Scientific name	Habit	Cover%	Aspect	Lat	Lon	AMT	APPT	LU code	Elev	Invasive index
Chukha	Logchina	Damchikha	Damchikha	6/23/2021	40	*E. crassipes*	Herb	80	NW	26.98	89.42	17.9483	3010.76	6	610	0.00
Chukha	Logchina	Damchikha	Damchikha	6/23/2021	40	*E. crassipes*	Herb	20	NW	26.98	89.42	18.0465	2976.33	19	789	0.00
Chukha	Logchina	Damchikha	Damchikha	6/23/2021	1	*A. adenophora*	Herb	20	NW	26.99	89.40	17.2331	2849.29	19	1551	6.57
Chukha	Logchina	Damchikha	Damchikha	6/23/2021	1	*A. adenophora*	Herb	21	NW	26.99	89.40	17.2116	2847.11	19	1556	6.57
Chukha	Logchina	Damchikha	Damchikha	6/23/2021	1	*A. adenophora*	Herb	10	NW	26.99	89.39	17.0741	2862.00	6	1715	6.57
Chukha	Logchina	Damchikha	Damchikha	6/23/2021	1	*A. adenophora*	Herb	5	N	26.99	89.40	17.1484	2854.63	6	1634	6.57
Chukha	Logchina	Damchikha	Damchikha	6/23/2021	1	*A. adenophora*	Herb	15	N	26.98	89.40	17.2832	2870.72	19	1607	6.57
Chukha	Logchina	Damchikha	Damchikha	6/23/2021	1	*A. adenophora*	Herb	50	NW	26.98	89.40	17.4806	2889.92	19	1430	6.57
Chukha	Logchina	Damchikha	Damchikha	6/23/2021	21	*M. micrantha*	Climber	1	NW	26.98	89.40	17.5117	2892.74	2	1376	4.17

Dzo = Dzongkhag; Lat = latitude; Long = longitude; AMT = annual mean temperature; APPT = annual precipitation; LU = land use; Elev = elevation

Appendix 3.2: IPS percent predicted presence by dzongkhag